REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE Sept 96

3. REPORT TYPE AND DATES COVERED
Technical Report

4. TITLE AND SUBTITLE

Development of Methods to Account for HCl and Cl_2 from Open Burning and Characterization of Emissions from the Open Burning of Three Selected Propellants

5. FUNDING NUMBERS

Contract No. DAAD09-92-D-0004

6. AUTHOR(S)
J.L Wilcox, B. Entezam, M.J. Molenaar, & T.R. Shreeve

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Physical Test Division
West Desert Test Center

Andrulis Research Corporation

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

SERDP
901 North Stuart St. Suite 303
Arlington, VA 22203

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

DPG Document No. DPG-TR-96-016

11. SUPPLEMENTARY NOTES
Technical report written for the U.S. Army Dugway Proving Ground, Dugway, UT 84022-5000. This work was supported in part by SERDP under Contract No. DAAD09-92-D-0004. The United States Government has a royalty-free license throughout the world in all copyrightable material contained herein. All other rights are reserved by the copyright owner.

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release: distribution is unlimited

12b. DISTRIBUTION CODE
A

13. ABSTRACT ***(Maximum 200 Words)***

An important class of propellant, explosive, and pyrotechnic (PEP) material that requires disposal permits is the chlorine-containing perchlorate explosives and propellants. Characterization of the recovery of HCl and Cl_2 is necessary to the development of emission factors for these materials. While characterization of emissions for many energetic materials (EMs) has proven feasible, chlorine-containing PEP materials pose a special challenge. Methods to account for chlorine emissions in PEP materials from open burning (OB) have eluded scientists except in small-scale bench tests.

19980709 120

14. SUBJECT TERMS
SERDP, PEP material, Energetic materials, Open burning (OB)

15. NUMBER OF PAGES
58

16. PRICE CODE N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
unclass.	unclass.	unclass.	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

123-1996

SERDP

DPG Document No. DPG-TR-96-016

DEVELOPMENT OF METHODS TO ACCOUNT FOR HCl AND Cl_2 FROM OPEN BURNING AND CHARACTERIZATION OF EMISSIONS FROM THE OPEN BURNING OF THREE SELECTED PROPELLANTS

By

James L. Wilcox

Physical Test Division
West Desert Test Center

Ben Entezam
Michael J Molenaar
Thomas Russell Shreeve

Andrulis Research Corporation
Contract No. DAAD09-92-D-0004

SEPTEMBER 1996

U. S. ARMY DUGWAY PROVING GROUND
DUGWAY, UTAH 84022-5000

Distribution Unlimited

DISPOSITION INSTRUCTIONS

Destroy this document when no longer needed. Do not return to the originator.

DESTRUCTION NOTICE

Destroy by any method that will prevent disclosure of contents or reconstruction of the document.

DISCLAIMER STATEMENT

The views, opinions, and/or findings in this report are those of the authors and should not be construed as an official Department of the Army position, unless so designated by other official documentation.

TRADE NAMES STATEMENT

The use of trade names in this document does not constitute an official endorsement or approval of the use of such commercial hardware or software. This document may not be cited for purposes of advertisement.

TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

TABLE		PAGE

LIST OF FIGURES

FIGURE PAGE

ACKNOWLEDGMENTS

The authors would like to thank Dr. William Mitchell, United States Environmental Protection Agency (EPA), Research Triangle Park, North Carolina; Radian Corporation, Research Triangle Park, North Carolina; Oregon Graduate Institute of Science and Technology (OGI), Beaverton, Oregon; Mountain States Analytical, Incorporated (MSAI), Salt Lake City, Utah; and Lockheed Corporation, DPG; for their contribution to the success of this study.

In addition, special thanks are given to the following Andrulis Research Corporation employees for their help in manuscript preparation and technical editing: Mr. Lacy Hancock, Ms. Cheri Martens, Ms. Carol Hanzelka, Ms. Linda Jorgensen, and Ms. Juliette Mestas.

INTENTIONALLY BLANK

EXECUTIVE SUMMARY

An important class of propellant, explosive, and pyrotechnic (PEP) material that requires disposal permits is the chlorine-containing perchlorate explosives and propellants. Characterization of the recovery of HCl and Cl_2 is necessary to the development of emission factors for these materials. While characterization of emissions for many energetic materials (EMs) has proven feasible, chlorine-containing PEP materials pose a special challenge. Methods to account for chlorine emissions in PEP materials from open burning (OB) have eluded scientists except in small-scale bench tests.

The Strategic Environmental Research and Development Program (SERDP), an interdepartmental activity which sponsors defense-related environmental research to meet the needs of the U.S. Department of Defense (DOD), U.S. Department of Energy (DOE), and the U.S. Environmental Protection Agency (EPA), sponsored this testing.

All testing was conducted in the PEP Thermal Treatment Evaluation Test Facility, commonly referred to as the BangBox, located at West Desert Test Center (WDTC), U.S. Army Dugway Proving Ground (DPG), Dugway, Utah.

The BangBox is an approximately 950-m^3 flexible hemisphere that uses the U.S. Army Armament, Munitions, and Chemical Command (AMCCOM) OB/open detonation (OD) thermal treatment emissions system successfully audited by several environmental agencies. This system consists of the BangBox facility and a network of laboratories specializing in the sampling and assaying of inorganic gases, volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and metals found in the atmosphere at trace levels.

The purpose of this testing was to develop methods and generate data that account for HCl and Cl_2 from OB, and to identify and quantify the emissions produced by OB of double-base propellant and the chlorine-containing nonaluminized ammonium perchlorate (AP) and aluminized AP propellants.

Results indicate that the real-time analyzer sampling for HCl accounted for an average of approximately 78 percent of the HCl or Cl_2 released. This is an achievement that accounts for nearly 27 percent more of the HCl or Cl_2 compared to the current standard EPA Method 26 using midget impingers.

Tests to characterize the absorption of chloride ions to the BangBox walls using swatches of BangBox fabric showed that chlorides were absorbed to the swatches. However, the quantities absorbed proved to be erratic and did not correlate to the amount of HCl or Cl_2 released, indicating that the methods used during this test were unsatisfactory in characterizing chloride absorption to the fabric of the BangBox walls.

The emissions were characterized by determining emission factors (the ratio of the mass of chemical species generated to the mass of EM of the PEP item burned and/or detonated) for several target analytes. The target analytes included 6 inorganic gases, more than 100 VOCs and SVOCs, and 15 metals. The emission factors can be used to predict the quantities of target pollutants generated from larger-scale, open-air OB/OD treatment of the materials tested. These data can be used to support Resource Conservation and Recovery Act (RCRA), Subpart X, permit applications for OB/OD treatment of unwanted PEP items contained within the demilitarization munitions inventory of DOD.

Data analyses also included calculation of emission factors for dioxins and furans from the burning of nonaluminized AP and aluminized AP and determination of percent chlorine recovered as HCl and Cl_2 from HCl releases and the burning of nonaluminized AP and aluminized AP.

Sampling instruments within the BangBox included high-volume continuous-flow samplers, SUMMA® canisters, and real-time gas analyzers. Laboratory assay was conducted using gas chromatography(GC)/flame ionization detection (FID), GC/mass spectrometry (MS), cold vapor atomic absorption (CVAA), and inductively coupled plasma (ICP)/optical emission spectrometry (OES).

The emission factors obtained from these trials are now being combined with those from other PEP materials previously studied in the BangBox. The resulting database will then be statistically examined to determine if PEP materials can be classified into "emission product families" based on the chemical composition of the PEP material. The statistical analysis will also determine: (1) if the number of background samples and/or field samples collected for each PEP material can be reduced or should be increased; (2) if the target analyte list, sampling methods, or the sample-collecting times should be changed; and (3) if there are artifact pollutants which should be removed from the test data. A database management system that will provide access to the BangBox data via the DOD Munitions Items Disposition Action System (MIDAS) is also being developed.

SECTION 1. INTRODUCTION

1.1 BACKGROUND

1.1.1 Limited Options for Disposal of Energetic Materials (EMs)

In maintaining a constant state of readiness, U.S. Department of Defense (DOD) installations manufacture and store a diverse inventory of energetic propellant, explosive, and pyrotechnic (PEP) materials. Those items that can no longer fulfill their original function, or are otherwise unwanted, must be safely treated and disposed of. Treatment methods such as incineration and deactivation, recovery, and recycling are inappropriate for many PEP materials because their composition is either unknown, unstable, or degraded. Furthermore, most PEP materials cannot be disassembled safely and the development of a deactivation, recovery, and recycling program cannot be financially justified. As a result, the only available treatment method for many PEP materials is open-air thermal destruction. Frequently referred to as open burning (OB) and open detonation (OD), this method has been proven safe, efficient, and effective (Reference 1).

1.1.2 The Requirement for Open Burning/Open Detonation (OB/OD) Emissions Data

Developing information to characterize the emissions produced by OB/OD treatment of energetic materials (EMs) is necessary for the acquisition of permits from the reigning state and/or the U.S. Environmental Protection Agency (EPA) regional agency as specified by the Resource Conservation and Recovery Act (RCRA) in 40 Code of Federal Regulations (CFR), Part 264, Subpart X and the Clean Air Act Amendments (References 2 and 3). The requirements of RCRA Subpart X permits include identifying the chemicals produced by the treatment method and the amount produced.

1.1.3 The BangBox Open Burning/Open Detonation (OB/OD) Test Program

The Department of the Army established a testing program at West Desert Test Center (WDTC), U.S. Army Dugway Proving Ground (DPG), Utah, to demonstrate compliance of OB/OD operations with federal and state environmental regulations. Tests were conducted in the Propellant, Explosive, and Pyrotechnic Thermal Treatment Evaluation and Test Facility, referred to as the BangBox. After DPG personnel concluded the field-testing phase of the BangBox study, EPA Region VIII personnel reviewed both methodology and data, and confirmed that the data collected from the BangBox testing facility closely represented actual field emissions and could support the emissions characterization necessary for the risk assessment requirements of the RCRA, Subpart X permits. The EPA Region VIII, Subpart X Coordinator wrote:

> This BangBox project represents a major step toward characterizing the emissions resulting from the open burning and/or open detonation of explosive wastes. Pursuant to 40 CFR 264.600, it is EPA Region VIII's policy to require all Resource Conservation and Recovery Act (RCRA) Part B permit applications submitted for units that OB/OD explosive hazardous waste to provide such emissions characterization...The BangBox procedure has the potential to provide the needed degree of characterization for many of the explosive wastes that are generated by the Department of Defense (DOD)...data generated [from] the BangBox tests...[are presently] viewed by EPA Region VIII as the best currently available data for each munition that is tested.

1.1.4 Chlorine-Containing Materials

While characterization of many EMs has proven feasible, chlorine-containing munitions pose a special challenge. Before this test, the means of accounting for all chlorine in the EM has been scientifically elusive except for very small-scale bench tests.

1.1.5 Testing of Ammonium Perchlorate (AP)-Based Materials

An important class of PEP material that requires disposal permits is perchlorate explosives and propellants. Characterization of the recovery of HCl and Cl_2 is critical to the development of emission factors for these materials. However, before perchlorate materials can be tested for emissions, methods need to be developed and data generated on the recovery of HCl and Cl_2 gas in the BangBox. The OB/OD technical steering committee (TSC) formed a concept for achieving a chlorine balance; this project constituted proof-of-principle testing of this concept. These recovery trials also provided one of the quality assurance (QA) stages necessary to ensure that emissions testing of perchlorate materials provide data of adequate quality for supporting regulatory compliance and permit activities.

1.1.6 Strategic Environmental Research and Development Program

The Strategic Environmental Research and Development Program (SERDP) is an inter-departmental activity which sponsors defense-related environmental research objectives to meet the needs of the DOD, U.S. Department of Energy (DOE), and the EPA. The testing discussed in this report focuses on items that have unique chemical and physical characteristics, such as chlorine, in their chemical composition.

1.2 TEST OBJECTIVES

a. Establish and evaluate methodologies for testing chemically unique PEP ordnance and waste items. The test materials consisted of propellants and waste production material generated during the manufacture of propellants. The test consisted of three phases: (1) the OB of double-base propellant to measure emissions released during thermal treatment of this type of propellant; (2) the controlled release of HCl from gas canisters to determine the fate and recoverability of chlorine within the BangBox; and (3) the OB of AP-based propellants to measure emissions released during the thermal treatment of chlorine containing PEP materials.

b. Compare real-time instruments with more elaborate and time-consuming sampling and laboratory assay methods for the measurement of HCl/Cl_2.

c. Characterize the amount of HCl/Ci_2 that is absorbed by the fabric of the BangBox through swatch testing.

SECTION 2. TEST ITEMS

2.1 DESCRIPTION

2.1.1 HCl Release

2.1.1.1 Purpose. HCl is a by-product of burning commonly used AP-based propellants. Despite OB thermal treatment being a major means of disposing of unwanted AP-based propellants, the amount of HCl released had never been accurately measured under conditions replicating open-air disposal. The BangBox provided a controlled environment for such measurements and conducting proof-of-principle testing. The precise release of HCl during this experiment was designed to provide information on how much can be recovered, thereby providing a baseline for measuring HCl emissions from chlorine-containing materials.

2.1.1.2 Water Nebulization. Except for the initial HCl release, deionized water was nebulized in the BangBox chamber just above the closed detonation pit in the center of the chamber to simulate the amount of water that the subsequent OB of AP-based propellants would generate.

2.1.1.3 Preparation for Testing. To minimize the potential reaction of HCl with metal materials, all equipment not directly involved in the trial was removed from the chamber before testing. A scrubber added to the transport tube at the chamber end of the tube protected real-time analyzers from the corrosive effects of HCl; chlorine monitors in the airlock had separate sampling tubes leading into the chamber. To provide the means of measuring absorptivity of the wall fabric, samples of BangBox fabric were cut into 15.2 by 15.2 cm swatches and suspended from a 14-kg test monofilament nylon line running 1.5 m above the floor between fans in the chamber.

2.1.1.4 Test Setup. One lecture bottle of 99 percent HCl was used for the first trial, and two lecture bottles were used for each of the following three trials. Teflon® tubing from each lecture bottle extended into the center of the chamber where, after the first trial during which the tubing moved around the chamber during release, the ends were anchored at floor level. The water nebulizer tubing led into the chamber center, and the nebulizer nozzle (selected for production of 1-µm droplets) was fixed approximately 1 m above the floor.

2.1.1.5 Test Execution. One trial was conducted each day for 4 days. As the valves of the bottles were opened, the bottles were immersed in hot water to counteract Joule-Thomson cooling as the gas released. Water was nebulized in the chamber at the same time as the HCl was released. Table 2.1 summarizes the material introduced into the chamber. The laboratory personnel responsible for analyzing the patches removed selected patches after each trial to generate data used in estimating the accumulated mass of HCl and the mass that could be attributed to each trial. Following removal of filters, the chamber was cleaned by washing the walls with water and vacuuming the floor. All water and solid residue was collected, labeled, and turned over to hazardous waste personnel for testing and disposal.

2.1.2 Double-Base Propellant

2.1.2.1 Purpose. The double-base propellant, a common propellant used in small rocket motors, typically contains 50 percent nitrocellulose and 35 percent nitroglycerine as its energetic components. The WDTC received the double-base propellant test material as a 5-kg block that required reduction to conform with the 2.27-kg limit on propellant burns in the BangBox. This propellant was tested to qualitatively support the use of BangBox methods for characterizing double-base propellants and, in the process, provide emission factor data regarding OB treatment. The nominal composition of the propellant is presented in Table 2.2.

Table 2.1. Material Introduced Into Chamber During HCl-Release Trials.

Date (1995)	HCl Released (g)	Water Nebulized (g)[a]
18 Jul	167.0	0
19 Jul	574.0	580
28 Jul	389.0	580
29 Jul	392.5	580

[a]Weights are approximate.

Table 2.2. Composition of Tested Double-Base Propellant

Analyte	Weight (percent)
Bismuth	0.02
Carbon	20.36
Hydrogen	2.97
Nitrogen	28.73
Oxygen	46.15
Zirconium	0.89
Lead	0.89
Tin	0.0001
Total	100.0

2.1.2.2 <u>Preparation for Testing</u>. A 5-kg block of propellant was divided in half with each segment further reduced until each conformed to the 2.27-kg limit for propellant burning in the BangBox chamber. Explosive experts cut a flap in the top of each block for subsequent insertion of an ignition charge.

2.1.2.3 <u>Test Setup</u>. A single propellant block was placed in a laboratory-cleaned 30.5 by 50.8 by 15.2 cm stainless steel burn pan resting on concrete blocks positioned in the center of the chamber floor. The ignition charge, composed of a fresh 81-mm mortar propellant bag loaded with 4 g of Hercules Unique™ smokeless powder and two M1A1 electric squibs, was inserted under the flap cut into the top of the block. The rubber insulation on the firing line was stripped so that less than 1 cm of insulation on each lead was directly exposed to burning propellant. A baffle was installed between the chamber's inflation blowers and the burn pan to prevent the output from the blowers from scattering particles of burning propellant or burn residue. This baffle remained in place for all subsequent propellant burn trials.

2.1.2.4 <u>Test Execution</u>. WDTC letter(s) of instruction (LOI) 24 and 25 contain instructions governing execution of double-base propellant burn trials. Two such trials were conducted on 27 July 1995.

2.1.3 Nonaluminized Ammonium Perchlorate (AP) Propellant

2.1.3.1 Purpose. The nonaluminized propellant was tested to provide information on the viability of current BangBox testing protocols to measure HCl and Cl_2 generated from the OB of nonaluminized propellants. EMs of this nature had not previously been investigated and characterized using the BangBox testing system. The nominal composition of the propellant is presented in Table 2.3.

2.1.3.2 Preparation for Testing. The WDTC received the nonaluminized AP propellant test material as a 5-kg block that required reduction to conform with the 2.27-kg limit on propellant burns in the BangBox. Explosives experts cut a flap in the top of each block for subsequent insertion of an ignition charge.

2.1.3.3 Test Setup. A single propellant block was placed in a laboratory-cleaned 30.5 by 50.8 by 15.2 cm stainless steel burn pan resting on concrete blocks positioned in the center of the chamber floor. The ignition charge, composed of a fresh 81-mm mortar propellant bag loaded with 4 g of Hercules Unique™ smokeless powder and two M1A1 electric squibs, was inserted under the flap cut into the top of the block. The rubber insulation on the firing line was stripped so that less than 1 cm of insulation on each lead was directly exposed to burning propellant.

2.1.3.4 Test Execution. WDTC LOI 24 and 26 contain instructions governing execution of nonaluminized AP propellant burns. Two such trials were scheduled. However, Trial 2 was rerun as Trial 2R because of a data acquisition system failure on Trial 2. The trials were conducted on different days to permit cleaning the chamber between trials.

2.1.4 Aluminized Ammonium Perchlorate (AP) Propellant

2.1.4.1 Purpose. The aluminized propellant was tested to provide information on the viability of the current OB testing protocols to measure HCl and Cl_2 and characterize the emissions generated from the OB of aluminized propellants. EMs of this nature had not been characterized using the BangBox testing system before this test series. The nominal composition of the propellant is presented in Table 2.4.

2.1.4.2 Preparation for Testing. The WDTC received the aluminized AP propellant test material as a 5-kg block that required reduction to conform with the 2.27-kg limit on propellant burns in the BangBox. However, preliminary burning of the propellant indicated that the energy released during OB was of such magnitude that the test material should be further reduced in size. Accordingly, the block was further divided into equal portions, each weighing about 1.2 kg. Explosive experts cut a flap in the top of each block for subsequent insertion of an ignition charge.

2.1.4.3 Test Setup. A single propellant block was placed in a laboratory-cleaned 30.5 by 50.8 by 15.2 cm stainless steel burn pan resting on four 1.1 by 1.1 by 0.06 m aluminum plates atop six concrete blocks positioned in the center of the chamber floor. The ignition charge, composed of a fresh 81-mm mortar propellant bag loaded with 4 g of Hercules Unique™ smokeless powder and two M1A1 electric squibs, was inserted under the flap cut into the top of the block. The rubber insulation on the firing line was stripped so that less than 1 cm of insulation on each lead was directly exposed to burning propellant.

2.1.4.4 Test Execution. WDTC LOI 24 and 27 contain instructions governing execution of aluminized AP propellant burns. Two such trials were conducted consecutively, one each day to permit cleaning the chamber between trials.

Table 2.3. Composition of Tested Nonaluminized Propellant.

Analyte	Weight (percent)
Chlorine	25.87
Carbon	11.27
Hydrogen	4.31
Nitrogen	10.35
Oxygen	47.31
Zirconium	0.89
Total	100.0

Table 2.4. Composition of Tested Aluminized Propellant.

Analyte	Weight (percent)
Aluminum	19
Bismuth	0.005
Chlorine	20.8
Carbon	10.1
Hydrogen	3.7
Nitrogen	8.3
Oxygen	38.1
Phosphorus	0.008
Total	100.0

2.2 TEST MATRIX

a. The 11 trials conducted during this test produced the data required for satisfying all test objectives. Two trials involved testing of a double-base propellant. four trials involved the release of HCl only (baseline chlorine assessment), and five trials involved the burn of AP-based propellants.

b. After equipment problems occurred during one of the trials for AP-based propellants, the test director determined that data from that trial were unusable and scheduled a third trial burn of AP-based propellant for the following day. The test matrix presented in Table 2.5 provides a synopsis of the testing activities.

Table 2.5. Test Matrix.

Date (1995)	Time (MDT[a])	Test Material	Supplemental Charge	Comments
18 Jul[b]	ND[c]	HCl release	None	
19 Jul[b]	ND	HCl release	None	Water nebulized
27 Jul	1029	Double-base propellant	Smokeless powder[d]	
27 Jul	1215	Double-base propellant	Smokeless powder	
28 Jul	1248	HCl release	None	Water nebulized
29 Jul	1045	HCl release	None	Water nebulized
31 Jul	1252	Nonaluminized AP[e] propellant	Smokeless powder	
01 Aug	1114	Nonaluminized AP propellant	Smokeless powder	Equipment failure
02 Aug	1102	Nonaluminized AP propellant	Smokeless powder	
03 Aug	1114	Aluminized AP propellant	Smokeless powder	
04 Aug	1147	Aluminized AP propellant	Smokeless powder	

[a]Mountain daylight time.
[b]Preliminary trials.
[c]No data.
[d]Hercules Unique™ smokeless powder, NSN 1376-00-X89-0013, was the igniter used for all burn trials.
[e]Ammonium perchlorate.

INTENTIONALLY BLANK

SECTION 3. TEST METHODOLOGY

3.1 OVERVIEW

The development of the BangBox testing facility at DPG was based on a series of tests conducted in other facilities and in open air (References 4 and 5). Emissions collected and assayed during those tests provided the framework for the instrumentation and sampling strategies now used in the BangBox facility. Results from BangBox testing can be scaled to provide emissions data for OB/OD of materials several times the quantities tested in the facility.

3.1.1 BangBox Test Facility. The BangBox test facility consists of the BangBox test chamber with attached airlock, a data acquisition system, a command post (CP), a munitions preparation trailer, and a portable munitions storage magazine.

3.1.1.1 BangBox Test Chamber

a. The BangBox test chamber sits on a concrete pad and is constructed of flexible polyvinylchloride (PVC)-coated polyester fabric in the shape of a 16-m diameter hemisphere. The test chamber is kept inflated at a volume of approximately 950 m^3 by two high-capacity blowers that inject ambient air into the chamber. The test chamber serves to capture the cloud from burning or detonation of test items where large fans circulate the air in the chamber to produce a homogenous cloud that is sampled by samplers positioned in the chamber and attached airlock.

b. The airlock is constructed of plywood and is attached to the side of the test chamber. It houses instruments and equipment and serves as a passageway to minimize the pressure loss to the test chamber. The chamber entryway contains a weighted overpressure hatch which protects the BangBox structure from rapid overpressure caused by the burning or detonation of test items.

c. Test items to be burned are placed in an stainless steel burn pan placed on a 1-m^2 steel plate burn pad located in the center of the test chamber. Items to be detonated are placed directly on the burn pad.

3.1.1.2 Data Acquisition System (DAS). The DAS consists of five computers connected to a local area network (LAN). Two of the computers are located in the BangBox airlock and provide data and video input to the LAN. The remaining computers are located in the CP and display or store data generated in the BangBox. The primary software used to collect and assemble raw data during this test was Lab Tech Notebook™ version 8.03 for Windows®.

3.1.1.3 Command Post (CP). The CP is located approximately 500 meters from the BangBox and contains a DAS file server, remote DAS monitors, detonation/ignition firing system (DIFS) station, closed-circuit television monitor (connected to the chamber camera), radio communication system, and a small work station for conducting test support.

3.1.1.4 Munitions Preparation Trailer. The munitions preparation trailer is used to weigh test items and prepare them for burning or detonation in the BangBox test chamber.

3.1.1.5 Portable Munitions Storage Magazine. A portable munitions storage magazine provides a means of temporarily storing small quantities of energetic test items and materials before testing.

3.2 TARGET ANALYTES

The cloud generated from the OB/OD treatment of test items was sampled for target inorganic gases, volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), metals, particulate matter less than ten microns diameter (PM_{10}), and for some items, dioxins, furans, and percent chlorine recovered as HCl and Cl_2. The following sections list the target analytes by group. The VOCs included nonmethane organic compounds (NMOCs), groups of compounds based on chemical structure, and a 42-component list of air toxics listed by the EPA.

3.2.1 Target Inorganic Gases

CO_2, CO, NO_X (NO and NO_2), O_3, SO_2, HCl, and SF_6 (released as a tracer during each trial).

3.2.2 Volatile Organic Compounds (VOCs)

Alkanes (Paraffins)

n-Heptane
2,4-Dimethylhexane
2-Methylheptane
2-Methylpentane
3-Methylpentane
Ethylcyclohexane
n-Hexane
i-Butane
Methylcyclopentane
n-Butane
2,4-Dimethylpentane
2,2-Dimethylpropane
Cyclohexane
n-Pentane
2,3-Dimethylpentane
Cyclopentane
3-Ethylhexane,3-Methylheptane
n-Octane
Ethane
2,3-Dimethylhexane
i-Pentane
Methane
2,2,4-Trimethylpentane
Methylcyclohexane
2,3,4-Trimethylpentane
n-Nonane
2,3-Dimethylbutane
Propane
2,2-Dimethylbutane
3-Methylhexane
2-Methylhexane
2,5-Dimethylhexane
2,2-Dimethylheptane
2,2,4-Trimethylhexane
n-Decane

Alkenes (Olefins)

Ethylene
2-Methyl-1-pentene
Propene
1-Butene
i-Butene
trans-2-hexene
3-Methyl-1-butene
Isoprene
1,3-Butadiene
trans-2-Pentene
cis-2-Butene
cis-2-Hexene
1-Pentene
2-Methyl-2-butene
1-Hexene
4-Methyl-1-pentene
trans-2-Butene
2-Methyl-2-pentene
2-Methyl-1-butene
Cyclopentene
cis-2-Pentene
cis-4-Methyl-2-pentene
2,4,4-Trimethyl-1-pentene
2,4,4-Trimethyl-2-pentene

Aromatics

Toluene
1,3,5-Trimethylbenzene
n-Propylbenzene
Styrene
i-Propylbenzene
Ethylbenzene
o-Xylene

m-Xylene & p-Xylene
1,2,4-Trimethylbenzene & sec-butylbenzene
Benzene
p-Ethyltoluene
m-Ethyltoluene
o-Ethyltoluene

Others

Acetylene
Nonmethane organic compounds (NMOCs)

Total unidentified hydrocarbons

3.2.3 Volatile Organic Compounds (VOCs) 42-Component List

Freon® 12
Methyl chloride
Freon® 114
Vinyl chloride
1,3-Butadiene
Methyl bromide
Ethyl chloride
Freon® 11
Vinylidene chloride
Dichloromethane
Allyl chloride
Freon® 113
1,1-Dichloroethane
cis-1,2-Dichloroethylene
Chloroform
1,2-Dichloroethane
Methyl chloroform
Benzene
Carbon tetrachloride
1,2-Dichloropropane
Trichloroethylene

cis-1,3-Dichloropropene
trans-1,3-Dichloropropene
1,1,2-Trichloroethane
Toluene
1,2-Dibromoethane
Tetrachloroethylene
Chlorobenzene
Ethylbenzene
m-, p-Xylene
Styrene
1,1,2,2-Tetrachloroethane
o-Xylene
p-Ethyl toluene
1,3,5-Trimethylbenzene
1,2,4-Trimethylbenzene
Benzyl chloride
m-Dichlorobenzene
p-Dichlorobenzene
o-Dichlorobenzene
1,2,4-Trichlorobenzene
Hexachlorobutadiene

3.2.4 Semivolatile Organic Compounds (SVOCs)

Phenol
bis(2-Chloroethyl)ether
2-Chlorophenol
1,3- Dichlorobenzene
1,4-Dichlorobenzene
Benzyl alcohol
1,2-Dichlorobenzene
2-Methylphenol (o-Cresol)
bis(2-Chloro-1-isopropyl)ether
3- and 4-Methylphenol (m- and p-Cresol)
Pentachloroethane

N-Nitrosodi-N-propylamine
Hexachloroethane
Pyridine
N-Nitrosodimethylamine
2-Picoline
N-Nitrosomethylethylamine
Methyl methanesulfonate
N-Nitrosodiethylamine
Ethyl methanesulfonate
Aniline
N-Nitrosopyrrolidine

Semivolatile Organic Compounds (SVOCs) (Cont'd)

Acetophenone
N-Nitrosomorpholine
o-Toluidine
Nitrobenzene
Isophorone
2,4-Dimethylphenol
2-Nitrophenol
bis(2-Chloroethoxy)methane
2,4-Dichlorophenol
1,2,4-Trichlorobenzene
Naphthalene
4-Chloroaniline
Hexachloro-1,3-butadiene
4-Chloro-3-methylphenol
2-Methylnaphthalene
N-Nitrosopiperidine
o,o,o-Triethylphosphorothioate
2,4-Dichlorophenol
Hexachloropropene
a,a-Dimethylphenethylamine
2,6-Dichlorophenol
1,4-Phenylenediamine
N-Nitrosodi-N-butylamine
Hexachlorocyclopentadiene
2,4,6-Trichlorophenol
2,4,5-Trichlorophenol
2-Chloronaphthalene
2-Nitroaniline
Dimethyl phthalate
2,6-Dinitrotoluene
Acenaphthylene
3-Nitroaniline
2,4-Dinitrophenol
Acenaphthene
4-Nitrophenol
2,3-Dinitrotoluene
Dibenzofuran
Diethyl phthalate
4-Chlorophenyl-phenyl ether
Fluorene
4-Nitroaniline
1,2,4,5-Tetrachlorobenzene
Isosafrole
Safrole
1,4-Naphthoquineone
1,3-Dinitrobenzene

Pentachlorobenzene
1-Naphthylamine
2,3,4,6-Tetrachlorophenol
2-Naphthylamine
Thionazin
5-Nitro-o-toluidine
4,6-Dinitro-2-methylphenol
N-Nitrosodiphenylamine
4-Bromophenyl-phenyl ether
Hexachlorobenzene
Pentachlorophenol
Phananthrene
Anthracene
Di-n-butyl phthalate
Fluoranthene
Tetraethyl dithiopyrophosphate
1,3,5-Trinitrobenzene
cis-Diallate
trans-Diallate
Pronamide
4-Nitroquinoline-1-oxide
Methapyrilene
Isodrin
Pyrene
Butylbenzyl phthalate
bis(2-Ethylhexyl) phthalate
3,3'-Dichlorobenzidine
Benzo(a)anthracene
Chrysene
p-(Dimethylamino)azobenzene
Chlorobenziliate
3,3'-Dimethylbenzidine
2-Acetylaminofluorene
Di-n-octyl phthalate
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(a)pyrene
Indeno(1,2,3-cd)pyrene
Dibenz(a,h)anthracene
Benzo(ghi)perylene
7,12-Dimethylbenz(a)anthracene
Hexachlorophene
Dimethoate
Phenacetin
4-Aminobiphenyl
Pentachloronitrobenzene

3.2.5 Metals

Aluminum	Lead
Antimony	Mercury
Arsenic	Nickel
Barium	Potassium
Cadmium	Sodium
Calcium	Titanium
Chromium	Zinc
Copper	

3.2.6 Particulate Matter Less Than Ten Microns in Diameter (PM_{10})

3.2.7 Dioxins and Furans

The analysis for dioxins and furans included total tetrachlorinated dibenzo-*p*-dioxin (TCDD), total pentachlorinated dibenzo-*p*-dioxin (PeCDD), total hexachlorinated dibenzo-*p*-dioxin (HxCDD), total heptachlorinated dibenzo-*p*-dioxin (HpCDD), octachlorinated dibenzo-*p*-dioxin (OCDD), 2378-TCDD, 1234678-HpCDD, total tetrachlorinated dibenzofuran (TCDF), total pentachlorinated dibenzofuran (PeCDF), total hexachlorinated dibenzofuran (HxCDF), total heptachlorinated dibenzofuran (HpCDF), octachlorinated dibenzofuran (OCDF), 2378-TCDF, 12378-PeCDF, 23478-PeCDF, 123478-HxCDF, 123678-HxCDF, 234678-HxCDF, 1234678-HpCDF, and 1234789-HpCDF. The nonaluminized AP and aluminized AP propellant burns were sampled for dioxins and furans.

3.2.8 Percent Chlorine Recovered as HCl and Cl_2

Samples were collected to measure HCl and Cl_2 concentrations to determine the percent chlorine recovered as HCl and Cl_2.

3.3 SAMPLING AND ASSAYING METHODS

3.3.1 Target Inorganic Gases

a. Concentrations of CO_2, CO, NO_X (NO and NO_2), O_3, SO_2, and HCl were measured using real-time gas analyzers. The analyzers were designed for continuous operation and provided real-time voltage data to the DAS for recording. Calibration of the analyzers followed manufacturer's procedures and instructions provided by EPA QA/quality control (QC) audit personnel.

b. Samples for measurement of CO_2 and CO were also collected using evacuated 6-L stainless steel SUMMA® canisters in accordance with (IAW) EPA Compendium TO-14 method. The samples were assayed using gas chromatograph/flame ionization detection (GC/FID) IAW EPA Compendium TO-14 method.

c. The real-time analyzers and SUMMA® canisters were located in the BangBox airlock and sampled the test chamber air through a stainless steel sampling manifold that extended into the test chamber. The sampling procedures for real-time analyzers are described in WDTC LOI 2. The sampling and assaying procedures using SUMMA® canisters and GC/FID are described in Oregon Graduate Institute of Science and Technology (OGI) LOI.

3.3.2 Volatile Organic Compounds (VOCs)

a. Samples for measurement of VOCs were collected using evacuated 6-L stainless steel SUMMA® canisters IAW EPA Compendium TO-12 or TO-14 methods.

b. The samples were assayed for NMOCs using GC/FID IAW EPA Compendium TO-12 method, groups of VOCs using GC/FID IAW EPA Compendium TO-14 method, and the 42-component list of VOCs using GC/mass spectrometry (MS) IAW EPA Compendium TO-14 method.

c. The SUMMA® canisters were located in the BangBox airlock and sampled the test chamber air through an stainless steel sampling manifold that extended into the test chamber. The sampling and assaying procedures using SUMMA® canisters and GC/FID and GC/MS are described in OGI LOI.

3.3.3 Semivolatile Organic Compounds (SVOCs)

a. Samples for measurement of SVOCs were collected using high-volume total suspended particle (TSP) air samplers equipped with quartz-fiber filters, pesticide sampler (PS)-1 air samplers equipped with quartz-fiber filters followed by a borosilicate glass cartridge containing XAD-2® resin, and high-volume PM_{10} air samplers equipped with quartz-fiber filters. The filter extracts were assayed for SVOCs using GC/MS IAW EPA Method 8270.

b. The samplers were located in the BangBox test chamber and sampled the test chamber air directly. The sampling and assaying procedures for SVOCs using high-volume TSP and PM_{10} samplers and GC/MS are described in Mountain States Analytical, Incorporated, (MSAI), LOI 2, 6, 13, 14, and 16. The sampling and assaying procedures for SVOCs using PS-1 samplers and GC/MS are described in Radian Corporation LOI 26, 27, 28, and 29.

3.3.4 Metals

a. Samples for measurement of metals were collected using high-volume TSP air samplers equipped with quartz-fiber filters and PM_{10} samplers equipped with quartz-fiber filters. The filter extracts were assayed for metals using inductively coupled plasma (ICP)/optical emission spectrometry (OES) IAW EPA SW-846 Methods 3050A and 6010A and cold vapor atomic absorption (CVAA) IAW EPA SW-846 Methods 3050A and 7471.

b. The samplers were located in the BangBox test chamber and sampled the test chamber air directly. The sampling and assaying procedures for metals using high-volume TSP and PM_{10} samplers and ICP/OES and CVAA are described in MSAI LOI 2, 16, 17, 18, and 19.

3.3.5 Particulate Matter Less Than Ten Microns in Diameter (PM_{10})

a. Samples for measurement of PM_{10} were collected using a PM_{10} sampler equipped with a quartz-fiber filter. The sampler was operated from approximately 15 minutes before burn/detonation initiation to approximately 35 minutes after burn/detonation initiation. The filters were weighed before and after each trial to determine the mass of PM_{10} produced.

b. The sampler had a flow rate monitor connected to the DAS. The DAS recorded voltages every second which were converted to flow rates (m^3/min) using a reference flow orifice.

c. The sampler was located in the BangBox test chamber and sampled the test chamber air directly.

3.3.6 Dioxins and Furans

a. Samples for measurement of dioxins and furans were collected using PS-1 air samplers equipped with quartz-fiber filters followed by a borosilicate glass cartridge containing XAD-2® resin. The filter extracts were assayed for dioxins and furans using GC/MS IAW EPA Method 8290X.

b. The samplers were located in the BangBox test chamber and sampled the test chamber air directly. The sampling and assaying procedures for dioxins and furans using PS-1 samplers and GC/MS are described in Radian Corporation LOI 26, 27, 28, 29, and 33.

3.3.7 Percent Chlorine Recovered as HCl and Cl_2

a. Samples for measurement of HCl and Cl_2 to determine the percent chlorine accounted for as HCl and Cl_2 were collected using six 30-ml dual midget impingers. The extracts were assayed for HCl and Cl_2 IAW EPA Method 26.

b. The impingers were located in the BangBox test chamber and sampled the test chamber air directly. The sampling and assaying procedures for HCl and Cl_2 using midget impingers are described in Radian Corporation LOI 39.

3.3.8 Sampling and Assaying Summary

a. Types of samplers and assay methods used to measure the concentrations of the target analytes are summarized in Table 3.1.

b. The LOI and laboratory results are available through WDTC upon request.

Table 3.1. Samplers and Assay Methods Used to Measure Concentrations of Target Analytes.

Analyte[a]	Sampler[b]	Sampler Location	Sampling Procedure[c]	Assay Method[d]
CO_2, CO, NO_X, O_3, SO_2, and HCl	Real-Time Analyzers	BangBox Airlock	WDTC LOI	Calibrated Voltage Data
CO_2 and CO	6-L SUMMA® Canisters	BangBox Airlock	OGI LOI	GC/FID; EPA Compendium TO-14
SF_6	0.85-L SUMMA® Canisters	BangBox Airlock	OGI LOI	GC/ECD; EPA Compendium TO-14
VOCs (NMOCs)	6-L SUMMA® Canisters	BangBox Airlock	OGI LOI	GC/FID; EPA Compendium TO-12
VOCs (Groups Based on Structure)	6-L SUMMA® Canisters	BangBox Airlock	OGI LOI	GC/FID; EPA Compendium TO-14
VOCs (42-Component List)	6-L SUMMA® Canisters	BangBox Airlock	OGI LOI	GC/MS; EPA Compendium TO-14
SVOCs	High-Volume TSP, PS-1 and PM_{10} Samplers	BangBox Test Chamber	MSAI LOI and Radian Corporation LOI	GC/MS; EPA Method 8270
Metals	High-Volume and PM_{10} Samplers	BangBox Test Chamber	MSAI LOI	ICP/OES and CVAA; EPA SW-846 Methods 3050A and 7471
PM_{10}	PM_{10}	BangBox Test Chamber	MSAI LOI	Mass Determination
Dioxins and Furans	PS-1 Samplers	BangBox Test Chamber	Radian Corporation LOI	GC/MS; EPA Method 8290X
HCl and Cl_2	30-ml Dual Train Midget Impingers	BangBox Test Chamber	Radian Corporation LOI	EPA Method 26

[a]VOCs - volatile organic compounds; NMOCs - nonmethane organic compounds; and SVOCs - semivolatile organic compounds; and PM_{10} - particulate matter less than ten microns in diameter.

[b]TSP - total suspended particulate; and PS - pesticide sampler.

[c]WDTC - West Desert Test Center; LOI - letter(s) of instruction; OGI - Oregon Graduate Institute of Science and Technology; and MSAI - Mountain States Analytical, Incorporated.

[d]GC - gas chromatography; FID - flame ionization detection; EPA - U.S. Environmental Protection Agency; ECD - electron capture detection; MS - mass spectrometry; ICP/OES - inductively coupled plasma/optical emission spectrometry; and CVAA - cold vapor atomic absorption.

SECTION 4. ANALYTICAL METHODS

4.1 OBJECTIVES

a. Determine a composite exponential rate of change to apply to measured concentrations of target chemical species, when applicable, to account for the following sources of sample dilution:

(1) Addition of ambient air into the chamber to maintain chamber inflation.

(2) Flow reduction in each high-volume, PS-1, and PM_{10} sampler.

(3) Addition of filtered air from the continuous flow samplers into the chamber.

b. Determine the instantaneous concentrations of target chemical species generated by the burn or detonation of test items.

c. Determine the volume of the BangBox test chamber during each test trial.

d. Correct sampler flow rates and calculated BangBox chamber volumes to standard temperature and pressure (STP).

e. Determine emission factors for target chemical species of material being tested.

f. Determine the percent chlorine recovered as HCl and Cl_2.

4.2 DATA REQUIRED

a. The concentration of SF_6 tracer gas released into the chamber and the concentration of SF_6 tracer gas measured at designated time intervals during the test.

b. Flow rates for continuous flow samplers over the sampling period.

c. Background concentrations of target chemical species in the BangBox chamber.

d. Temperature and barometric pressure measurements of the chamber during the test.

e. Concentrations of target chemical species resulting from burn or detonation of the test item.

f. Mass of chlorine burned or detonated and measured concentrations of HCl and Cl_2.

4.3 DATA ANALYSES

a. Composite exponential rate of change to apply to measured concentrations of target chemical species to account for sources of sample dilution.

(1) Correction for Dilution Because of Chamber Pressure Maintenance. The SF_6 concentration data collected during the test were used to model the dilution rate within the chamber because of maintenance of chamber pressure. The data were fit to an exponential model (Equation 4.1), using the method of least squares, to determine the dilution rate from the inflation system. An example of the actual data and model from a trial are shown in Figure 4.1.

$$C(t) = C(0)\ e^{k_1 t} \qquad \text{Equation 4.1}$$

where $C(t)$ = concentration of target chemical species at time = t
t = time from burn/detonation initiation or tracer release
$C(0)$ = concentration of target chemical species at t = 0
k_1 = exponential rate of change per unit of time due to air added to BangBox to keep the chamber inflated

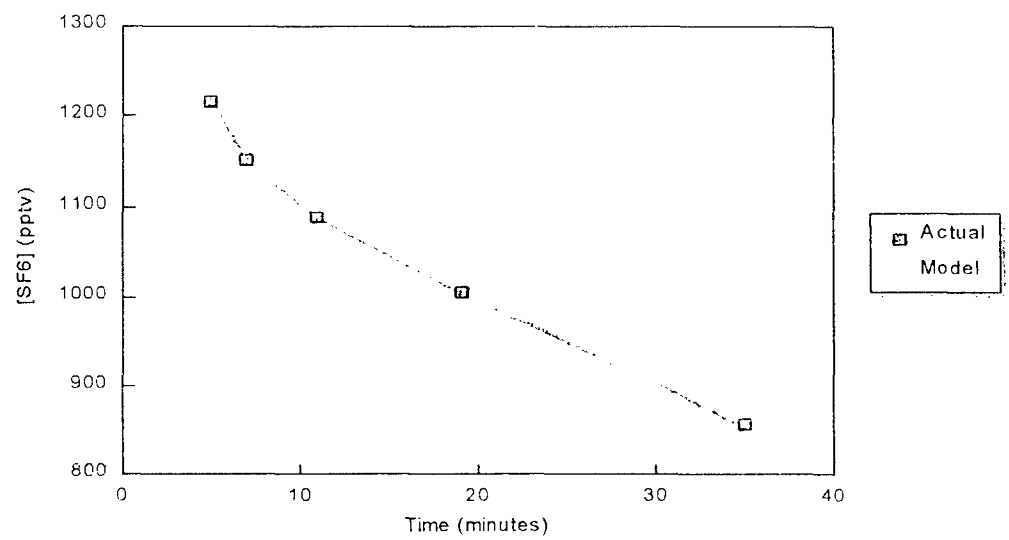

Figure 4.1. Concentration of SF_6 Tracer Gas Versus Time

(2) Correction for Reduction of Flow in Individual High-volume, PS-1, and PM_{10} Samplers During the Sampling Period. The collection of chemical species and particulate matter on the filters of the high-volume, PS-1, and PM_{10} samplers results in a decrease in sampler flow rate over the sampling period. An exponential model (Equation 4.2) was fit to the individual sampler flow rate over time using the method of least squares to model the flow rate reduction occurring in individual high-volume, PS-1, and PM_{10} samplers over the sampling period (Figure 4.2). When filters from individual samplers were combined for laboratory analysis and the results were reported as mass/number of filters, the flow rates of the individual samplers were summed for each second and the resulting combined flow rate was fit to an exponential model using the method of least squares.

$$F(t) = F(0)\ e^{k_2 t}$$ Equation 4.2

where F(t) = flow rate of individual sampler at time = t
t = time from burn/detonation initiation
F(0) = flow rate of individual sampler at t = 0
k_2 = exponential rate of change per unit of time due to reduction in individual (or combined) sampler flow rate

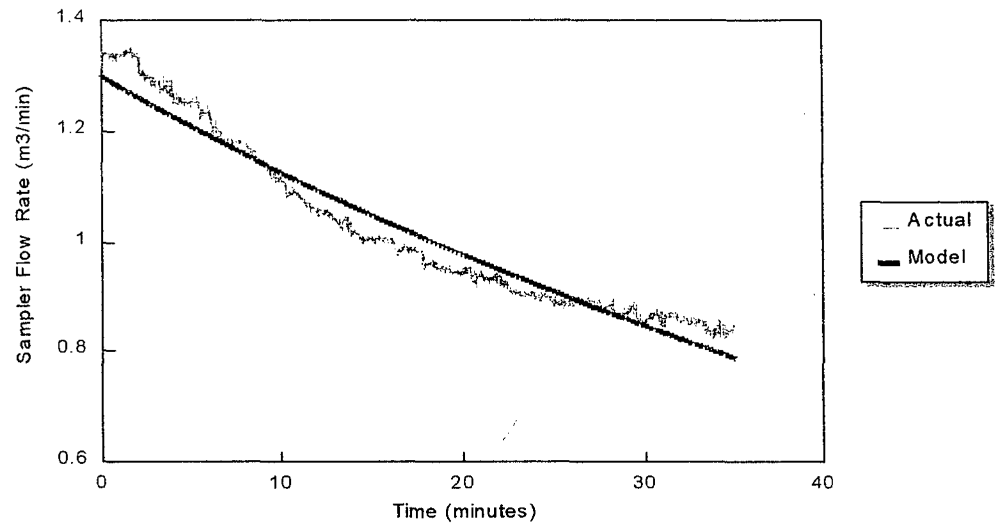

Figure 4.2. Sampler Flow Rate Versus Time.

(3) Correction For Dilution Because of Addition of Filtered Air From All High-volume, PS-1, and PM_{10} Samplers in the Chamber. The flow rate data for the high-volume, PS-1, and PM_{10} samplers were summed for each second from burn/detonation initiation to the end of the sampling period. An exponential model (Equation 4.3) was fit to these data using the method of least squares to determine the dilution rate of measured concentrations because of the addition of filtered air from the samplers. An example of the actual data and model from a trial are shown in Figure 4.3.

$$\sum F(t) = \sum F(0)\ e^{k_3 t}$$ Equation 4.3

where ΣF(t) = sum of flow rates for all high-volume, PS-1, and PM_{10} samplers at time = t
t = time from burn/detonation initiation
ΣF(0) = sum of flow rates for all high-volume, PS-1, and PM_{10} samplers at time = 0
k_3 = exponential rate of change per unit of time due to addition of filtered air from all high-volume, PS-1, and PM_{10} samplers in the chamber

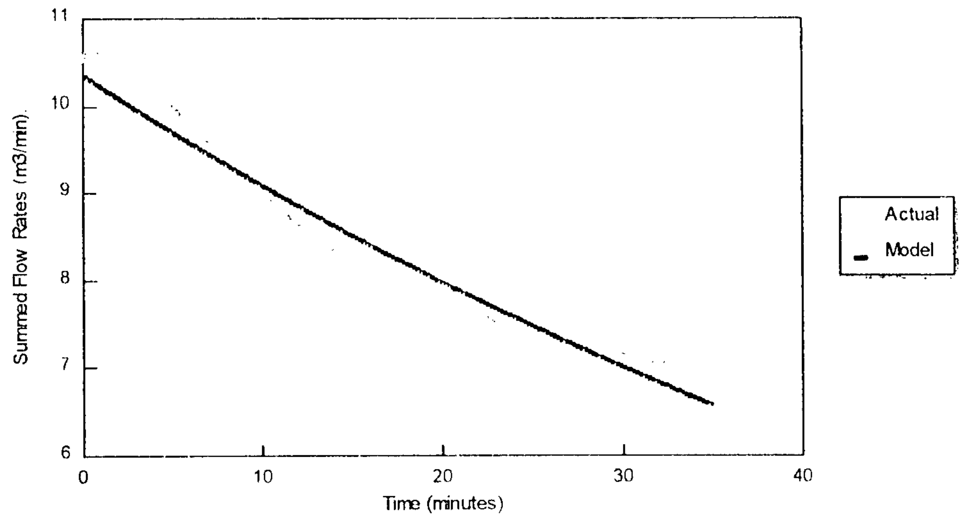

Figure 4.3. Summed Flow Rates For All Samplers Versus Time

(4) The Composite Exponential Rate of Change. The composite exponential rate of change for a target chemical species depends on its sources of sample dilution. For instance, all measured concentrations of chemical species have been diluted by chamber ventilation, but not all have been diluted by flow reduction in the samplers or the addition of filtered air from the samplers (i.e., inorganic gases). The following relationship (Equation 4.4) shows how individual exponential rates of change from Equations 4.1, 4.2, and 4.3 can be combined to determine a composite model for a chemical species whose measured sample concentration has been diluted from all three dilution sources. The measured concentration is a function of all three dilution sources and the equations used to model them individually can be combined to characterize the concentration over time. Table 4.1 summarizes the exponential rates of change used to model the different classes of compounds for their sources of dilution based on the type of samplers used to collect and measure them.

$$\begin{aligned} C_s(t) &= C_s(0) \left(e^{k_1 t} * e^{k_2 t} * e^{k_3 t} \right) \\ &= C_s(0)\, e^{(k_1 + k_2 + k_3) t} \\ &= C_s(0)\, e^{k_c t} \end{aligned} \qquad \text{Equation 4.4}$$

where $C_S(t)$ = concentration of target chemical species at time = t

t = time after burn/detonation initiation or tracer release

$C_S(0)$ = undiluted (corrected) concentration of target chemical species

k_1 = exponential rate of change per unit of time because of air added to BangBox to keep chamber inflated

k_2 = exponential rate of change per unit of time due to reduction in sampler flow rate

k_3 = exponential rate of change per unit of time due to addition of filtered air from the continuous samplers into the chamber

k_C = composite exponential rate of change per unit time due to all three dilution sources ($= k_1 + k_2 + k_3$)

Table 4.1. Composite Exponential Rates of Change Used to Model Classes of Compounds.

Class of Compound	Type of Sampler Used	Composite Exponential Rate of Change (k_c)
Target inorganic gases	Real-time analyzer and SUMMA® canister	NA[a]
VOCs[b]	SUMMA® canister	k_1
SVOCs[c]	High-volume, PS[d]-1, and PM_{10}[e]	$k_1 + k_2 + k_3$
Metals	High-volume and PM_{10}	$k_1 + k_2 + k_3$
PM_{10}	PM_{10} sampler	$k_1 + k_2 + k_3$
Dioxins and Furans	PS-1	$k_1 + k_2 + k_3$
HCl and Cl_2	Dual train impinger	$k_1 + k_2$

[a]Not applicable (see Paragraphs 4.3.c and 4.3.e).
[b]Volatile organic compounds.
[c]Semivolatile organic compounds.
[d]Pesticide sampler.
[e]Particulate matter less than ten microns in diameter.

b. The time average concentration of target chemical species collected over time (t_1 to t_2) can be expressed as:

$$\bar{C}_S = \frac{\int_{t_1}^{t_2} C_S(0)\, e^{k_C t}\, dt}{t_2 - t_1} \qquad \text{Equation 4.5}$$

where $\bar{C}_S$ = average concentration of target chemical species
$C_S(0)$ = undiluted (instantaneous) concentration of target chemical species
k_c = composite exponential rate of change per unit time (Table 4.1)

Integrating equation 4.5 over the interval t_1 to t_2 yields:

$$\bar{C}_S = \frac{C_S(0)}{k_C} * \frac{e^{k_C t_2} - e^{k_C t_1}}{t_2 - t_1} \qquad \text{Equation 4.6}$$

and rearranging terms yields:

$$C_S(0) = \frac{k_c * (t_2 - t_1)}{e^{k_C t_2} - e^{k_C t_1}} * \bar{C}_S \qquad \text{Equation 4.7}$$

where the correction factor (CF) to account for dilution sources is

$$CF = \frac{k_c * (t_2 - t_1)}{e^{k_C t_2} - e^{k_C t_1}} \qquad \text{Equation 4.8}$$

and the average concentration (corrected for volume sampled prior to burn/detonation initiation and background concentration) is

$$\bar{C}_S = \frac{M_{S_{trial}} - \left(\frac{M_{S_{bkgd}}}{V_{S_{bgkd}}} * V_{S_{b4db}} \right)}{V_{S_{trial}}} - \frac{M_{S_{bkgd}}}{V_{S_{bgkd}}} \qquad \text{Equation 4.9}$$

where M_{Strial} = measured mass of target chemical species during trial
V_{Strial} = volume of air sampled to collect mass of target chemical species during trial
M_{Sbkgd} = measured mass of target chemical species before trial
V_{Sbkgd} = volume of air sampled to collect mass of target chemical species before trial
V_{Sb4bd} = volume of air sampled before burn/detonation initiation.

The volumes sampled by individual samplers were estimated using numerical integration of the recorded flow rate data.

c. The instantaneous concentrations of target inorganic gases emitted were determined by fitting an exponential model [$C(t) = C(0)\, e^{kt}$] to the real-time analyzer data, corrected for background concentrations, and extrapolating to burn/detonation initiation time (t = 0) (Figure 4.4). This concentration (measured as ppmv) was used along with the equation of state for an ideal gas (Equation 4.10) to determine the mass of target inorganic gas emitted.

$$P\, V_{gas} = n\, R\, T \qquad \text{Equation 4.10}$$

where P = pressure of the gas (expressed as atm)
V_{gas} = volume of the gas
n = number of moles of gas
R = the universal gas constant = 0.0821 L atm/mol K
T = temperature of the gas (expressed as K)

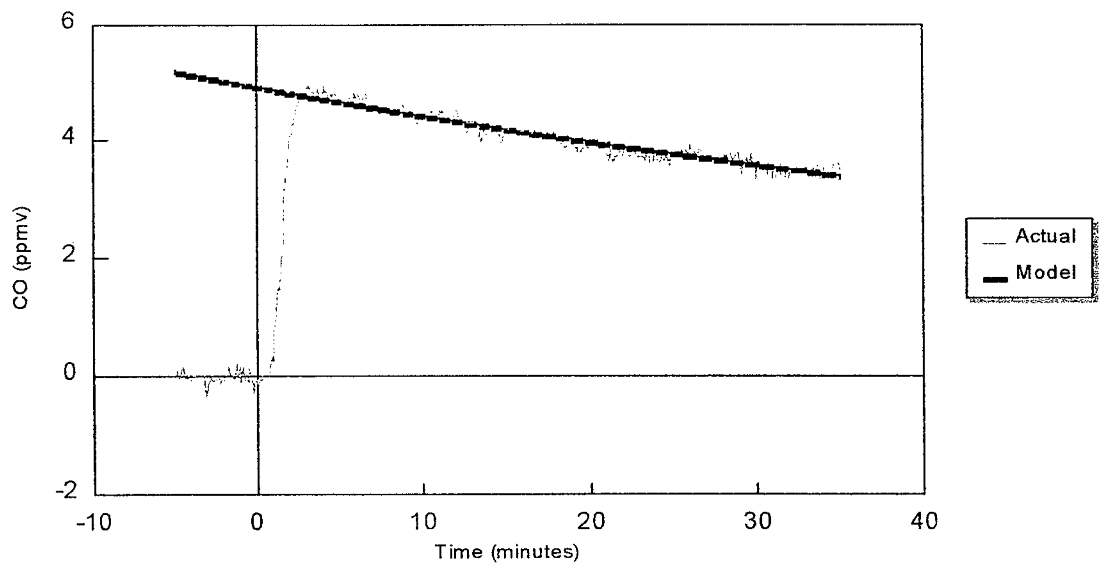

Figure 4.4. Concentration of a Target Inorganic Gas (CO) Versus Time.

The volume of the gas is related to its concentration (measured as ppmv) and the volume of the BangBox chamber (V_{BB}) through the expression

$$V_{gas} = ppmv * V_{BB}$$ Equation 4.11

and the number of moles of gas is related to its mass (m) and its molecular weight (MW) through the expression

$$n = \frac{m}{MW}$$ Equation 4.12

Substituting these expressions into Equation 4.10 and rearranging terms yields the following expression for the mass of target inorganic gas emitted:

$$m = \frac{P * ppmv * V_{BB} * MW}{R * T}$$ Equation 4.13

d. BangBox chamber volume

(1) The SF_6 concentration data were used to estimate the volume of the chamber using the following relationship:

$$V_{BB} = \frac{C_{gas} * V_{gas}}{C_{BB}} \qquad \text{Equation 4.14}$$

where V_{BB} = BangBox chamber volume
C_{gas} = concentration of SF_6 gas in canister before release
V_{gas} = volume of SF_6 gas in canister before release
C_{BB} = corrected concentration of SF_6 gas in chamber after release

(2) The concentration of SF_6 tracer gas in the test chamber after release was corrected using Equation 4.1. The calculated chamber volumes were adjusted to STP (25°C and 760 mm Hg).

e. Emission factors for all target chemical species (excluding inorganic gases) were calculated using the following relationship:

$$EF_S = \frac{C_S(0) * V_{BB}}{MEM} \qquad \text{Equation 4.15}$$

where EF_S = emission factor for target chemical species
$C_S(0)$ = corrected concentration of target chemical species (using Equation 4.7)
V_{BB} = BangBox chamber volume
MEM = mass of energetic material

Emission factors for target inorganic gases were calculated using the following relationship:

$$EF_g = \frac{m}{MEM} \qquad \text{Equaton 4.16}$$

where EF_g = emission factor for target inorganic gas
m = mass of target inorganic gas (using Equation 4.13)
MEM = mass of energetic material

The mass of target inorganic gas was not corrected for sources of dilution because it was assumed that any source of dilution, including ventilation of the BangBox chamber, would be corrected for when the real-time analyzer data were extrapolated to determine the instantaneous gas concentrations.

f. The percent chlorine recovered as HCl and Cl_2 was determined using the following relationship:

$$\% \ Chlorine \ Recovered = \frac{M_{Chlorine} \ Emitted}{M_{Chlorine} \ Initial} * 100 \qquad \text{Equation 4.17}$$

where $M_{Chlorine}$ Emitted = mass of chlorine emitted as HCl or Cl_2
$M_{Chlorine}$ Initial = mass of chlorine in test item prior to burn/detonation

INTENTIONALLY BLANK

SECTION 5. RESULTS

5.1 SF_6 TRACER GAS

The results from the SF_6 tracer gas used for each trial to determine the volume of the BangBox test chamber and the exponential rate of change of target analyte concentrations from maintenance of the BangBox chamber pressure are presented in Table 5.1.

Table 5.1. Calculated BangBox Chamber Volumes and Exponential Rates of Change (k_1) from Chamber Pressure Maintenance Dilution Model.

Material Released	Trial Number	Trial Date (1995)	Volume STP[a] (m^3)	Exponential Rate of Change (min^{-1})	Correlation Coefficient (r^2)
HCl Preliminary	1	18 Jul	745.1	-0.0133	0.9983
	2	19 Jul	754.2	-0.0137	0.9979
Double-Base Propellant	1	27 Jul	-[b]	-0.0109	0.9953
	2	27 Jul	731.4	-0.0106	0.9984
HCl	1	28 Jul	716.2	-0.0088	0.9686
	2	29 Jul	739.0	-0.0089	0.9462
Nonaluminized Propellant	1	31 Jul	742.9	-0.0096	0.9995
	2[c]	1 Aug	760.3	-0.0103	0.9955
	2R	2 Aug	744.7	-0.0110	0.9890
Aluminized Propellant	1	3 Aug	727.7	-0.0088	0.9973
	2	4 Aug	733.8	-0.0073	0.9989
Average			739.5	-0.0103	0.9895
Standard Deviation			12.9	0.0018	0.0161

[a]Standard temperature and pressure.
[b]SF_6 filled canister suspected of leaking before release. Volume of chamber not used in average.
[c]Data acquisition system failed because of an electrical ground loop problem. Trial rerun as 2R.

5.2 RECOVERY OF HCl FROM HCl RELEASES AND AMMONIUM PERCHLORATE (AP)-BASED PROPELLANT BURNS

a. The results of the HCl and Cl_2 recovery accounting for chlorine using the TECO Model 15 gas filter correlation HCl analyzer for HCl and EPA Method 26 using midget impingers to recover HCl and Cl_2 are presented in Table 5.2.

b. A plot showing the HCl concentrations as measured by real-time analyzers versus time for the HCl release trials are presented in Figure 5.1. The precipitous drops for plots at approximately 17 and 37 minutes are because of trial endings.

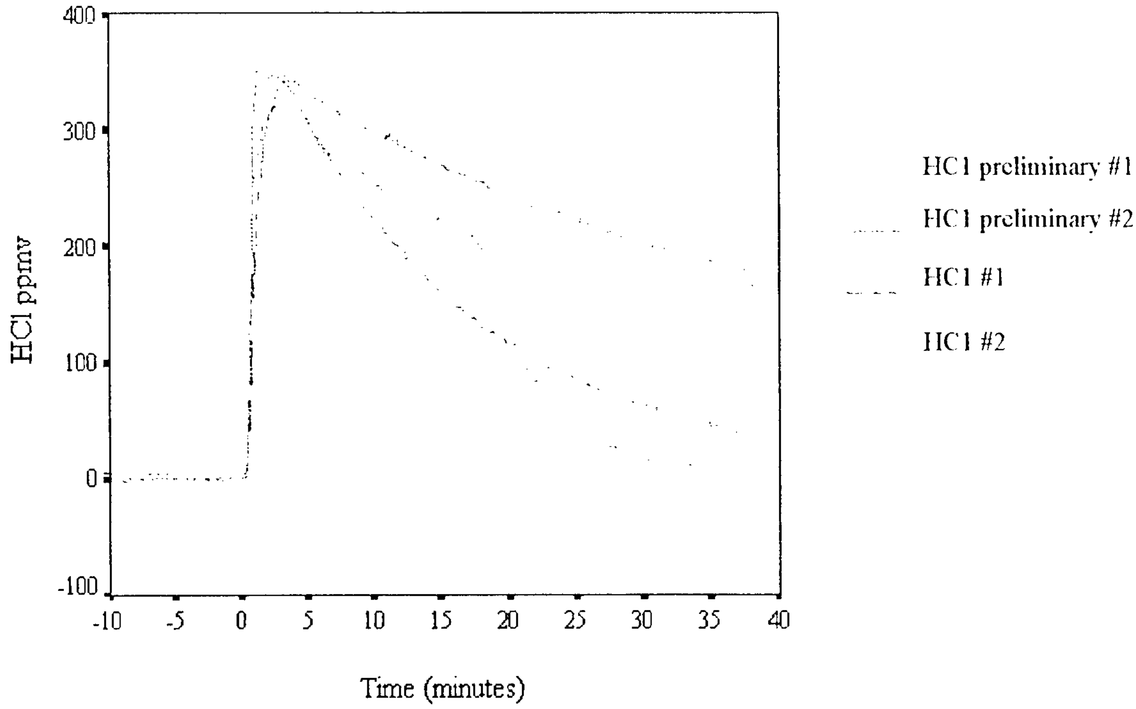

Figure 5.1. HCl Concentrations Versus Time for the HCl Releases.

c. A plot showing the HCl and CO_2 concentrations as measured by real-time analyzers versus time for the nonaluminized and aluminized AP propellant burns is presented in Figures 5.2 and 5.3, respectively. CO_2 is plotted because it is a stable compound after formation and provides a decay rate for comparison to the HCl decay rate.

d. The results indicate that both the TECO Model 15 gas filter correlation HCl analyzer and EPA Method 26 for HCl using midget impingers correlate very strongly with the amount of HCl or Cl_2 released in the BangBox chamber ($r=.972$, p-val <0.001 for the TECO Model 15; $r=.895$, p-val < 0.001 for EPA Method 26 (HCl)).

5.3 CHAMBER FABRIC ABSORPTION

5.3.1 Chlorides. Chlorides were found on all swatches exposed. However, a calculation of the correlation coefficient relating mass of HCl or Cl_2 released and the mass of chloride recovered on the swatch material indicated no correlation ($r=.199$, p-val$=.638$ for old material; $r=-0.080$, p-val$=.851$ for new material). The mass of HCl or Cl_2 released in the chamber, the mass recovered on the swatch material and the percent of HCl or Cl_2 accounted for as chloride are presented in Table 5.3.

5.3.2 Bromides. Bromides were not detected on any sample from any of the test materials. There was a total of 14 swatches on the HCl releases, 6 swatches on the nonaluminized AP burns, and 6 swatches on the aluminized AP burns.

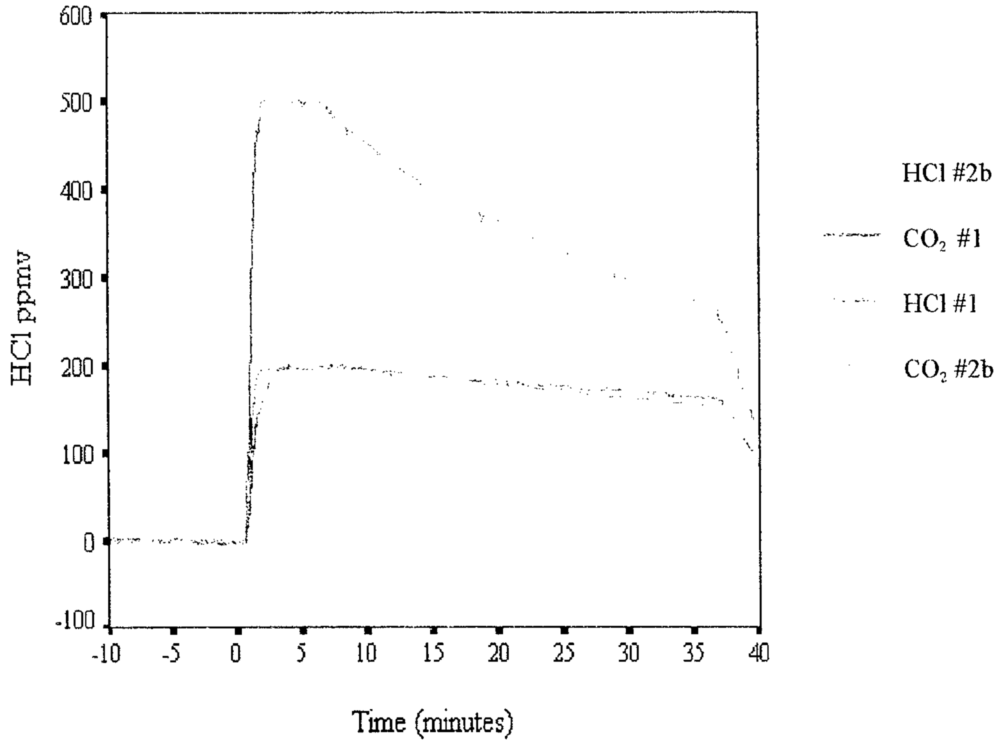

Figure 5.2. HCl and CO_2 Concentrations Versus Time for the Non-aluminized Ammonium Perchlorate (AP) Burns.

5.3.3 Nitrates. Nitrates were detected on one of six swatches from the old material and one of eight swatches from the new material during the four HCl releases. Nitrates were not detected on the six swatches on the nonaluminized AP burns or on the six swatches on the aluminized AP burns.

5.3.4 Sulfates. Sulfates were detected on four of six swatches from the old material and none of the eight swatches from the new material during the four HCl releases. Sulfates were not detected on the six swatches on the nonaluminized AP burns. On the aluminized AP burns, one swatch of the new material had a very small quantity detected below the level of quantification for sulfates.

5.4 EMISSION FACTORS

5.4.1 Double-Base Propellant

5.4.1.1 Target Inorganic Gases. Emission factors for target gases (measured with real-time analyzers or sampled with SUMMA® canisters and assayed using GC/FID) from the burning of double-base propellant are presented in Table 5.4.

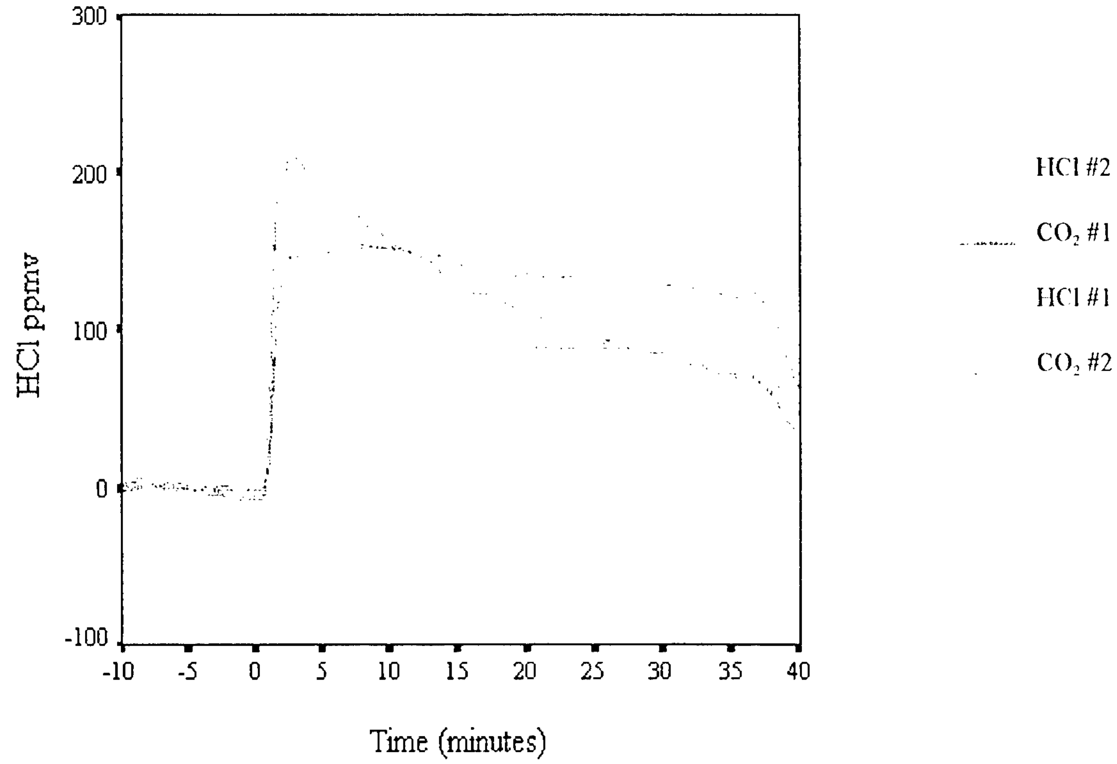

Figure 5.3. HCl and CO_2 Concentrations Versus Time for the Aluminized Ammonium Perchlorate (AP) Burns.

5.4.1.2 Volatile Organic Compounds (VOCs)

a. Emission factors for VOCs (sampled with SUMMA® canisters and assayed using EPA Method TO-12 or TO-14 using GC/FID) from the burning of double-base propellant are presented in Table 5.5.

b. Emission factors for VOCs (sampled with SUMMA® canisters and assayed using EPA Method TO-14 using GC/MS) from the burning of double-base propellant are presented in Table 5.6.

5.4.1.3 Semivolatile Organic Compounds (SVOCs)

a. Emission factors for SVOCs (sampled with high-volume and PM_{10} samplers with quartz-fiber filters and assayed using EPA Method 8270 using GC/MS) from the burning of double-base propellant are presented in Table 5.7.

b. Emission factors for SVOCs (sampled with PS-1 samplers with quartz-fiber filters and XAD-2® resin and assayed using EPA Method 8270 using GC/MS) from the burning of double-base propellant are presented in Table 5.8.

Table 5.2. Percent of Chlorine Recovered as HCl and Cl_2 from the Release of 99 Percent HCl and the Burning of Nonaluminized and Aluminized Ammonium Perchlorate (AP) Propellant.

Material Released	Method	Sampling Train	Trial 1 (%)	Trial 2 (%)
HCl Preliminary	TECO Model 15 (HCl)	NA[a]	72.14	69.54
HCl	TECO Model 15 (HCl)	NA	81.77	80.47
	HCl by Method 26	Train 1	57.53	54.49
		Train 2	58.04	64.39
	Cl_2 by Method 26	Train 1	1.99	0.00
		Train 2	0.12	1.61
Nonaluminized AP Propellant	TECO Model 15 (HCl)	NA	85.60	82.55
	HCl by Method 26	Train 1	62.75	65.45
		Train 2	62.08	64.28
	Cl_2 by Method 26	Train 1	1.47	1.27
		Train 2	1.51	1.21
Aluminized AP Propellant	TECO Model 15 (HCl)	NA	75.96	76.36
	HCl by Method 26	Train 1	46.20	46.14
		Train 2	50.24	48.53
	Cl_2 by Method 26	Train 1	1.35	0.91
		Train 2	1.03	0.95

[a]Not applicable.

5.4.1.4 Metals. Emission Factors for metals (sampled with high-volume and PM_{10} samplers and assayed using ICP/OES or CVAA) from the burning of double-base propellant are presented in Table 5.9.

5.4.1.5 Particulate Matter Less Than Ten Microns in Diameter (PM_{10}). The emission factors for PM_{10} from the burning of double-base propellant for Trials 1 and 2 are 1.85e-02 g/g and 1.94e-02 g/g, respectively. The average is 1.90e-02 g/g with a standard deviation of 6.36e-04 g/g.

5.4.1.6 Burn Pan Residues. The burn pan residue remaining from the burning of double-base propellant was analyzed to determine the emission factors in the form of residue for SVOCs which are presented in Table 5.10 and for metals which are presented in Table 5.11.

5.4.2 Nonaluminized Ammonium Perchlorate (AP) Propellant. Trial 2 was rerun as Trial 2R. The DAS failed on Trial 2 because of an electrical ground loop problem.

5.4.3 Target Inorganic Gases. Emission factors for target gases (measured with real-time analyzers or sampled with SUMMA® canisters and assayed using GC/FID) from the burning of nonaluminized AP propellant are presented in Table 5.12.

Table 5.3. Estimated Mass of Chloride Absorbed on Fabric Material Burning with Percent HCl/Cl_2 Accounted for as HCl.

		Old Swatch Material				New Swatch Material			
	Mass of HCl/Cl_2 released (g)	Mass of Chloride Recovered (g)		Percent of HCl/Cl_2 Accounted For		Mass of Chloride Recovered (%)		Percent of HCl/Cl_2 Accounted For	
Material Released		Swatch 1	Swatch 2	Swatch 1	Swatch 2	Swatch 1	Swatch 2	Swatch 1	Swatch 2
HCl Preliminary Release No. 1	167	NS[a]	60.62	NA[b]	42.30	10.37	9.11	6.21	5.46
HCl Preliminary Release No. 2	574	NS	102.69	NA	17.89	11.62	9.74	2.02	1.70
HCl Release No. 1	389	10.86	17.19	2.79	4.42	4.08	4.71	1.05	1.21
HCl Release No. 2	392	6.79	5.43	1.73	1.39	4.08	4.71	1.04	1.20
Nonaluminized AP[c] Propellant Burn No. 1	587.25	NS	13.12	NA	2.23	9.11	7.23	1.55	1.23
Nonaluminized AP Propellant Burn No. 2R	587.25	NS	14.02	NA	2.39	10.05	10.37	1.71	1.77
Aluminized AP Propellant Burn No. 1	472.16	NS	7.24	NA	1.53	4.56	4.87	0.97	1.03
Aluminized AP Propellant Burn No. 2	472.16	NS	4.07	NA	0.86	7.54	6.91	1.60	1.46

[a]No sample.
[b]Not applicable.
[c]Ammonium Perchlorate.

Table 5.4. Emission Factors for Target Inorganic Gases from the Burning of Double-Base Propellant.

Analyte	Trial 1 (g/g)	Trial 2 (g/g)	Average (g/g)	SD[a] (g/g)
Real-Time Analyzer				
CO_2	7.52e-01	7.80e-01	7.66e-01	2.00e-02
CO	1.76e-03	1.82e-03	1.79e-03	4.23e-05
NO	1.67e-03	1.65e-03	1.66e-03	1.30e-05
NO_2	9.03e-05	1.04e-04	9.71e-05	9.58e-06
SO_2	2.59e-05	2.41e-05	2.50e-05	1.25e-06
SUMMA® Canister				
CO_2	8.00e-01	8.13e-01	8.06e-01	9.17e-03
CO	1.77e-03	1.83e-03	1.80e-03	4.22e-05

[a]Standard deviation.

5.4.4 Volatile Organic Compounds (VOCs)

a. Emission factors for VOCs (sampled with SUMMA® canisters and assayed using EPA Method TO-12 or TO-14 using GC/FID) from the burning of nonaluminized AP propellant are presented in Table 5.13.

b. Emission factors for VOCs (sampled with SUMMA® canisters and assayed using EPA Method TO-14 using GC/MS) from the burning of nonaluminized AP propellant are presented in Table 5.14.

5.4.4.1 Semivolatile Organic Compounds (SVOCs)

a. Emission factors for SVOCs (sampled with high-volume and PM_{10} samplers with quartz-fiber filters and assayed using EPA Method 8270 GC/MS) from the burning of nonaluminized AP propellant are presented in Table 5.15.

b. Emission factors for SVOCs sampled with PS-1 samplers with quartz-fiber filters and XAD-2 resin and assayed using EPA Method 8270 using GC/MS) from the burning of nonaluminized AP propeilant are presented in Table 5.16.

5.4.4.2 Metals. Emission factors for metals (sampled with high-volume and PM_{10} samplers and assayed using ICP/OES or CVAA) from burning of double-base propellant are presented in Table 5.17.

5.4.4.3 Particulate Matter Less Than Ten Microns in Diameter (PM_{10}). The emission factors for PM_{10} from the burning of nonaluminized AP propellant for Trials 1 and 2R are 1.14e-02 g/g and 1.82e-02 g/g, respectively. The average is 1.48e-02 g/g with a standard deviation of 4.81e-03 g/g.

Table 5.5. Emission Factors for Volatile Organic Compounds (VOCs) (Assayed using GC/FID[a]) from the Burning of Double-Base Propellant.

Analyte	Trial 1 (g/g)	Trial 1 (g/g)	Average (g/g)	SD[b] (g/g)
Alkanes (Paraffins)	3.70e-07	BDL[c]	<3.70e-07	ND[d]
Alkenes (Olefins)	4.00e-06	6.20e-06	5.10e-06	1.56e-06
Aromatics	2.93e-06	3.74e-06	3.33e-06	5.72e-07
Total Unidentified Hydrocarbons	2.69e-06	3.61e-06	3.15e-06	6.50e-07
Total Nonmethane Hydrocarbons	9.99e-06	1.32e-05	1.16e-05	2.24e-06
Methane	BDL	BDL	ND	ND
1,3-Butadiene	BDL	BDL	ND	ND
Benzene	5.05e-07	9.84e-07	7.45e-07	3.39e-07
Toluene	6.73e-07	3.28e-07	5.01e-07	2.44e-07
Styrene	BDL	BDL	ND	ND
Total Nonmethane Organic Compounds	1.78e-05	2.66e-05	2.22e-05	6.23e-06

[a]Gas chromatography/flame ionization detection.
[b]Standard deviation.
[c]Below detection limit.
[d]Not determinable.

5.4.4.4 Dioxins and Furans. Table 5.18 presents the emission factors for dioxins and furans (sampled with a PS-1 sampler and assayed using GC/MS) from the burning of nonaluminized AP propellant.

5.4.4.5 Burn Pan Residues. The burn pan residue remaining from the burning of nonaluminized AP propellant was analyzed to determine the emission factors in the form of residue for SVOCs which are presented in Table 5.19 and for metals which are presented in Table 5.20.

5.4.5 Aluminized Ammonium Perchlorate (AP) Propellant

5.4.5.1 Target Organic Gases. Emission factors for target organic gases (measured with real-time analyzers or sampled with SUMMA® canisters and assayed using GC/FID) from the burning of aluminized AP propellant are presented in Table 5.21.

5.4.5.2 Volatile Organic Compounds (VOCs)

a. Emission factors for VOCs (sampled with SUMMA® canisters and assayed using EPA Method TO-12 or TO-14 using GC/FID) from the burning of aluminized AP propellant are presented in Table 5.22.

b. Emission factors for VOCs (sampled with SUMMA® canisters and assayed using EPA Method TO-14 using GC/MS) from the burning of aluminized AP propellant are presented in Table 5.23.

Table 5.6. Emission Factors for Volatile Organic Compounds (VOCs) (Assayed using GC/MS[a]) from the Burning of Double-Base Propellant.

Analyte	Trial 1 (g/g)	Trial 2 (g/g)	Average (g/g)	SD[b] (g/g)
Freon® 12	1.01e-07	BDL[c]	<1.01e-07	ND[d]
Methyl chloride	1.01e-07	6.57e-08	8.33e-08	2.50e-08
Methyl bromide	3.37e-08	6.57e-08	4.97e-08	2.26e-08
Freon® 11	BDL	6.57e-08	<6.57e-08	ND
Vinylidene chloride	BDL	3.28e-08	<3.28e-08	ND
Methylene chloride	1.92e-06	BDL	<1.92e-06	ND
Freon® 113	BDL	3.28e-08	<3.28e-08	ND
Methylchloroform	BDL	3.28e-08	<3.28e-08	ND
Benzene	1.21e-06	1.22e-06	1.21e-06	4.58e-09
Carbon tetrachloride	3.37e-08	3.28e-08	3.33e-08	6.12e-10
Toluene	5.05e-07	6.23e-07	5.64e-07	8.35e-08
Chlorobenzene	3.37e-08	9.84e-08	6.61e-08	4.58e-08
Ethylbenzene	2.69e-07	4.60e-07	3.64e-07	1.35e-07
m-,p-Xylene	8.08e-07	1.18e-06	9.92e-07	2.61e-07
o-Xylene	3.03e-07	5.25e-07	4.14e-07	1.57e-07
p-Ethyltoluene	6.73e-08	1.32e-07	9.94e-08	4.54e-08
1,3,5-Trimethylbenzene	BDL	3.28e-08	<3.28e-08	ND
1,2,4-Trimethylbenzene	6.73e-08	6.57e-08	6.65e-08	1.15e-09

[a]Gas chromatography/mass spectrometry.
[b]Standard deviation.
[c]Below detection limit.
[d]Not determinable.

5.4.5.3 Semivolatile Organic Compounds (SVOCs)

a. Emission factors for SVOCs (sampled with high-volume and PM_{10} samplers with quartz-fiber filters and assayed using EPA Method 8270 GC/MS) from the burning of aluminized AP propellant are presented Table 5.24.

b. Emission factors for SVOCs (sampled with PS-1 samplers with quartz-fiber filters and XAD-2 resin and assayed using EPA Method 8270 GC/MS) from the burning of aluminized AP propellant are presented in Table 5.25.

5.4.5.4 Metals. Emission Factors for metals (sampled with high-volume and PM_{10} samplers and assayed using ICP/OES or CVAA) from the burning of aluminized AP propellant are presented in Table 5.26.

Table 5.7. Emission Factors for Semivolatile Organic Compounds (SVOCs) (Sampled with High-Volume and PM_{10}[a] Samplers) from the Burning of Double-Base Propellant.

Analyte	Trial 1 (g/g)	Trial 2 (g/g)	Average (g/g)	SD[b] (g/g)	PM_{10} Sampler Trial 1 (g/g)
Phenol	BDL[c]	6.23e-08	<6.23e-08	ND[d]	BDL
Benzyl alcohol	9.13e-08	9.38e-08	9.25e-08	1.74e-09	8.08e-08
2-Nitrophenol	2.72e-07	5.36e-08	1.63e-07	1.54e-07	1.64e-08
Dimethyl phthalate	1.05e-07	1.06e-07	1.05e-07	5.82e-10	8.86e-08
4-Nitrophenol	2.09e-07	2.63e-07	2.36e-07	3.82e-08	BDL
Diethyl phthalate	4.33e-08	4.96e-08	4.65e-08	4.49e-09	6.32e-08
N-Nitrosodiphenylamine	9.52e-08	4.88e-08	7.20e-08	3.28e-08	4.63e-08
Di-n-butyl phthalate	1.08e-07	1.37e-07	1.23e-07	2.08e-08	1.48e-07
Fluoranthene	BDL	3.70e-08	<3.70e-08	ND	1.57e-08
Pyrene	1.05e-08	3.02e-08	2.03e-08	1.39e-08	1.84e-08
Butylbenzyl phthalate	4.18e-08	5.36e-08	4.77e-08	8.35e-09	BDL
Benzo(a)anthracene	BDL	2.15e-08	<2.15e-08	ND	1.36e-08
Chrysene	BDL	3.21e-08	<3.21e-08	ND	2.04e-08
Di-n-octyl phthalate	2.93e-08	4.19e-08	3.56e-08	8.93e-09	1.98e-08

[a]Particulate matter less than ten microns in diameter.
[b]Standard deviation.
[c]Below detection limit.
[d]Not determinable.

5.4.5.5 Particulate Matter Less Than Ten Microns in Diameter (PM_{10}). The emission factors for PM_{10} from the burning of aluminized AP propellant for Trials 1 and 2 are 4.13e-01 g/g and 4.31e-01 g/g, respectively. The average is 4.22e-01 g/g with a standard deviation of 1.27e-02 g/g.

5.4.5.6 Dioxins and Furans. Table 5.27 presents the emission factors for dioxins and furans (sampled with a PS-1 sampler and assayed using GC/MS) from the burning of aluminized AP propellant.

5.4.5.7 Burn Pan Residues. The burn pan residue remaining from the burning of aluminized AP propellant was analyzed to determine the emission factors in the form of residue for SVOCs which are presented in Table 5.28 and for metals which are presented in Table 5.29

Table 5.8. Emission Factors for Semivolatile Organic Compounds (SVOCs) (Sampled with PS[a]-1 Samplers) from the Burning of Double-Base Propellant.

Analyte	Trial 1 (g/g)	Trial 2 (g/g)	Average (g/g)	SD[b] (g/g)
Benzyl alcohol	2.18e-06	6.56e-06	4.37e-06	3.10e-06
Acetophenone	5.92e-07	6.59e-07	6.26e-07	4.74e-08
Naphthalene	1.97e-07	2.88e-07	2.43e-07	6.43e-08
2-Methylnaphthalene	2.09e-08	5.25e-08	3.67e-08	2.23e-08
Dimethyl phthalate	1.55e-07	1.72e-07	1.64e-07	1.20e-08
Acenaphthylene	BDL[c]	7.67e-08	<7.67e-8	ND[d]
Diethyl phthalate	BDL	8.16e-07	<8.16e-7	ND
Diphenylamine	1.01e-07	BDL	<1.01e-7	ND
bis(2-Ethylhexyl) phthalate	9.14e-07	3.89e-07	6.52e-07	3.71e-07
Di-n-octyl phthalate	BDL	6.12e-07	<6.12e-7	ND

[a]Pesticide sampler
[b]Standard deviation.
[c]Below detection limit.
[d]Not determinable.

Table 5.9. Emission Factors for Metals from the Burning of Double-Base Propellant.

Analyte	Trial 1 (g/g)	Trial 2 (g/g)	Average (g/g)	SD[a] (g/g)	PM_{10}[b] Sampler Trial 1 (g/g)
Aluminum	1.64e-07	2.70e-07	2.17e-07	7.47e-08	BDL[c]
Antimony	BDL	BDL	ND[d]	ND	BDL
Arsenic	BDL	BDL	ND	ND	BDL
Barium	4.08e-08	4.03e-08	4.05e-08	4.17e-10	BDL
Cadmium	BDL	BDL	ND	ND	BDL
Calcium	BDL	BDL	ND	ND	BDL
Chromium	1.64e-08	BDL	<1.64e-08	ND	2.62e-08
Copper	2.67e-06	3.18e-04	1.61e-04	2.23e-04	2.42e-05
Lead	5.75e-03	5.54e-03	5.64e-03	1.46e-04	1.82e-03
Mercury	9.45e-10	9.42e-10	9.43e-10	2.50e-12	BDL
Nickel	BDL	BDL	ND	ND	BDL
Potassium	1.23e-05	1.18e-05	1.21e-05	4.10e-07	4.80e-06
Sodium	2.96e-05	2.96e-05	2.96e-05	4.48e-08	9.34e-08
Titanium	5.42e-08	5.42e-08	5.42e-08	2.37e-11	8.22e-09
Zinc	1.76e-06	9.01e-06	5.39e-06	5.13e-06	2.33e-06

[a]Standard deviation.
[b]Particulate matter less than ten microns in diameter.
[c]Below detection limit.
[d]Not determinable.

Table 5.10. Concentrations of Semivolatile Organic Compounds (SVOCs) in the Double-Base Propellant Burn Pan Residue.

Analyte	Trials 1 and 2 (combined) (μg/kg)
Benzyl alcohol	520
2-Methylphenol (o-Cresol)	400
Diethyl phthalate	500
Di-n-butyl phthalate	2200
bis(2-Ethylhexyl) phthalate	350

Table 5.11. Concentrations of Metals in the Double-Base Propellant Burn Pan Residue.

Analyte	Trials 1 and 2 (combined) (mg/kg)
Aluminum	480
Antimony	BDL[a]
Arsenic	30
Barium	5.8
Cadmium	BDL
Calcium	400
Chromium	21
Copper	1900
Lead	56000
Mercury	BDL
Nickel	23
Potassium	140
Sodium	620
Titanium	60
Zinc	440

[a]Below detection limit.

Table 5.12. Emission Factors for Target Inorganic Gases from the Burning of Nonaluminized Ammonium Perchlorate (AP) Propellant.

Analyte	Trial 1 (g/g)	Trial 2R (g/g)	Average (g/g)	SD[a] (g/g)
Real-Time Analyzer				
CO_2	4.13e-01	4.21e-01	4.17e-01	5.69e-03
CO	1.24e-04	1.29e-04	1.26e-04	3.77e-06
NO	4.14e-03	3.88e-03	4.01e-03	1.85e-04
NO_2	4.25e-03	4.73e-04	2.36e-03	2.67e-03
SO_2	1.10e-04	1.05e-04	1.07e-04	3.37e-06
O_3	1.61e-02	2.12e-02	1.87e-02	3.66e-03
SUMMA® Canister				
CO_2	4.29e-01	4.42e-01	4.36e-01	9.28e-03
CO	1.57e-04	1.73e-04	1.65e-04	1.17e-05

[a]Standard deviation.

Table 5.13. Emission Factors for Volatile Organic Compounds (VOCs) (Assayed using GC/FID[a]) from the Burning of Nonaluminized Ammonium Perchlorate (AP) Propellant.

Analyte	Trial 1 (g/g)	Trial 2R (g/g)	Average (g/g)	SD[b] (g/g)
Alkanes (Paraffins)	3.61e-06	4.32e-06	3.97e-06	5.02e-07
Alkenes (Olefins)	1.19e-05	1.22e-05	1.21e-05	2.12e-07
Aromatics	1.02e-06	3.16e-06	2.09e-06	1.51e-06
Total Unidentified Hydrocarbons	2.96e-05	1.56e-05	2.26e-05	9.90e-06
Total Nonmethane Hydrocarbons	4.61e-05	3.52e-05	4.07e-05	7.71e-06
Methane	2.04e-06	5.83e-06	3.94e-06	2.68e-06
1,3-Butadiene	BDL[c]	BDL	ND[d]	ND
Benzene	1.70e-07	1.71e-07	1.71e-07	7.07e-10
Toluene	7.47e-07	2.75e-06	1.75e-06	1.42e-06
Styrene	BDL	BDL	ND	ND
Total Nonmethane Organic Compounds	5.30e-05	6.31e-05	5.81e-05	7.14e-06

[a]Gas chromatography/flame ionization detection.
[b]Standard deviation.
[c]Below detection limit.
[d]Not determinable.

Table 5.14. Emission Factors for Volatile Organic Compounds (VOCs) (Assayed using GC/MS[a]) from the Burning of Nonaluminized Ammonium Perchlorate (AP) Propellant.

Analyte	Trial 1 (g/g)	Trial 2R (g/g)	Average (g/g)	SD[b] (g/g)
Freon® 12	BDL[c]	2.73e-07	<2.73e-07	ND[d]
Methyl chloride	6.77e-07	1.12e-06	8.99e-07	3.13e-07
Vinyl chloride	1.02e-07	2.04e-07	1.53e-07	7.21e-08
1,3-Butadiene	6.80e-08	3.43e-08	5.12e-08	2.38e-08
Ethyl chloride	4.76e-07	7.21e-07	5.99e-07	1.73e-07
Freon® 11	3.40e-08	1.37e-07	8.55e-08	7.28e-08
Vinylidene chloride	3.40e-08	6.87e-08	5.14e-08	2.45e-08
Methylene chloride	1.05e-06	5.66e-06	3.36e-06	3.26e-06
Freon® 113	3.40e-08	3.43e-08	3.42e-08	2.12e-10
1,1-Dichloroethane	3.40e-08	3.43e-08	3.42e-08	2.12e-10
Chloroform	7.47e-07	1.07e-06	9.09e-07	2.28e-07
1,2-Dichloroethane	3.40e-08	BDL	<3.40e-08	ND
Methylchloroform	3.40e-08	BDL	<3.40e-08	ND
Benzene	3.06e-07	7.21e-07	5.14e-07	2.93e-07
Carbon tetrachloroide	1.40e-06	2.12e-06	1.76e-06	5.09e-07
Toluene	3.74e-07	1.41e-06	8.92e-07	7.33e-07
Tetrachloroethylene	3.40e-08	4.97e-06	2.50e-06	3.49e-06
Chlorobenzene	BDL	3.43e-08	<3.43e-08	ND
Ethylbenzene	3.40e-08	3.43e-08	3.42e-08	2.12e-10
m-,p-Xylene	BDL	6.87e-08	<6.87e-08	ND
Benzyl chloride	3.74e-07	4.80e-07	4.27e-07	7.50e-08

[a]Gas chromatography/mass spectrometry.
[b]Standard deviation.
[c]Below detection limit.
[d]Not determinable.

Table 5.15. Emission Factors for Semivolatile Organic Compounds (SVOCs) (Sampled with High-Volume and PM_{10}[a] Samplers) from the Burning of Nonaluminized Ammonium Perchlorate (AP) Propellant.

Analyte	Trial 1 (g/g)	Trial 2R (g/g)	Average (g/g)	SD[b] (g/g)	PM_{10} Sampler Trial 1 (g/g)	PM_{10} Sampler Trial 2R (g/g)	PM_{10} Sampler Average (g/g)
bis(2-Chloroethyl)ether	BDL[c]	BDL	ND[d]	ND	BDL	1.71e-08	<1.71e-08
Dimethyl phthalate	7.82e-08	9.72e-08	8.77e-08	1.34e-08	BDL	BDL	ND
4-Nitrophenol	1.57e-06	1.69e-06	1.63e-06	8.81e-08	BDL	2.88e-07	<2.88e-07
Diethyl phthalate	5.21e-08	5.33e-08	5.27e-08	8.01e-10	BDL	BDL	ND
Di-n-butyl phthalate	3.57e-08	5.96e-08	4.76e-08	1.69e-08	BDL	9.76e-09	<9.76e-09
Butylbenzyl phthalate	1.17e-08	BDL	<1.17e-08	ND	BDL	1.99e-09	<1.99e-09
bis(2-Ethylhexyl) phthalate	2.01e-08	BDL	<2.01e-08	ND	BDL	BDL	ND
Di-n-octyl phthalate	8.74e-08	1.37e-07	1.12e-07	3.50e-08	BDL	8.82e-09	<8.82e-09

[a]Particulate matter less than ten microns in diameter.
[b]Standard deviation.
[c]Below detection limit.
[d]Not determinable.

Table 5.16. Emission Factors for Semivolatile Organic Compounds (SVOCs) (Sampled with PS[a]-1 Samplers) from the Burning of Nonaluminized Ammonium Perchlorate (AP) Propellant.

Analyte	Trial 1 (g/g)	Trial 2R (g/g)	Average (g/g)	SD[b] (g/g)
2-Chlorophenol	5.18e-06	7.46e-06	6.32e-06	1.61e-06
Benzyl alcohol	6.29e-07	1.48e-06	1.05e-06	6.02e-07
Acetophenone	2.94e-07	2.29e-07	2.62e-07	4.60e-08
2-Nitrophenol	5.04e-06	4.92e-06	4.98e-06	8.49e-08
2,4-Dichlorophenol	1.85e-06	3.57e-06	2.71e-06	1.22e-06
Naphthalene	BDL[c]	2.62e-07	<2.62e-07	ND[d]
2,6-Dichlorophenol	BDL	5.32e-07	<5.32e-07	ND
Dimethyl phthalate	8.78e-08	8.25e-08	8.52e-08	3.75e-09
4-Nitrophenol	9.92e-07	1.16e-06	1.08e-06	1.19e-07
Di-n-butyl phthalate	4.10e-08	3.54e-07	1.98e-07	2.21e-07
bis(2-Ethylhexyl) phthalate	1.04e-06	2.05e-07	6.23e-07	5.90e-07

[a]Pesticide sampler.
[b]Standard deviation.
[c]Below detection limit.
[d]Not determinable.

Table 5.17. Emission Factors for Metals from the Burning of Nonaluminized Ammonium Perchlorate (AP) Propellant.

Analyte	Trial 1 (g/g)	Trial 2R (g/g)	Average (g/g)	SD[a] (g/g)	PM_{10}[b] Sampler Trial 1 (g/g)	PM_{10} Sampler Trial 2R (g/g)	PM_{10} Sampler Average (g/g)	PM_{10} Sampler SD (g/g)
Aluminum	8.98e-06	6.60e-06	7.79e-06	1.69e-06	4.17e-06	5.52e-06	4.84e-06	9.54e-07
Antimony	BDL[c]	1.17e-06	<1.17e-06	ND[d]	BDL	BDL	ND	ND
Arsenic	BDL	BDL	ND	ND	BDL	BDL	ND	ND
Barium	2.67e-07	2.19e-07	2.43e-07	3.44e-08	1.87e-07	1.82e-07	1.85e-07	3.24e-09
Cadmium	BDL	BDL	ND	ND	BDL	BDL	ND	ND
Calcium	6.41e-04	6.83e-04	6.62e-04	2.96e-05	4.10e-04	4.41e-04	4.25e-04	2.21e-05
Chromium	6.99e-06	8.54e-06	7.77e-06	1.09e-06	4.17e-06	5.44e-06	4.80e-06	8.97e-07
Copper	5.45e-05	9.61e-05	7.53e-05	2.94e-05	2.95e-05	6.61e-05	4.78e-05	2.58e-05
Lead	3.74e-06	1.71e-06	2.72e-06	1.43e-06	3.36e-06	BDL	<3.36e-06	ND
Mercury	BDL	BDL	ND	ND	2.45e-09	1.58e-09	2.02e-09	6.15e-10
Nickel	1.11e-05	2.28e-05	1.69e-05	8.28e-06	6.68e-06	1.49e-05	1.08e-05	5.81e-06
Potassium	5.64e-05	6.21e-05	5.92e-05	4.08e-06	3.34e-05	4.04e-05	3.69e-05	4.97e-06
Sodium	8.12e-05	7.15e-05	7.63e-05	6.84e-06	6.76e-05	6.82e-05	6.79e-05	4.01e-07
Titanium	3.40e-07	3.36e-07	3.38e-07	2.27e-09	2.10e-07	2.95e-07	2.53e-07	6.02e-08
Zinc	3.31e-07	1.17e-06	7.49e-07	5.92e-07	1.06e-06	1.92e-06	1.49e-06	6.07e-07

[a]Standard deviation.
[b]Particulate matter less than ten microns in diameter.
[c]Below detection limit.
[d]Not determinable.

Table 5.18. Emission Factors for Dioxins and Furans from the Burning of Nonaluminized Ammonium Perchlorate (AP) Propellant.

Analyte	Trial 1 (g/g)	Trial 2 (g/g)	Average (g/g)	SD[a] (g/g)
Dioxins				
2378-TCDD	BDL[b]	BDL	ND[c]	ND
1234678-HpCDD	BDL	1.49e-12	<1.49e-12	ND
OCDD	BDL	4.48e-12	<4.48e-12	ND
Furans				
2378-TCDF	BDL	BDL	ND	ND
12378-PeCDF	BDL	BDL	ND	ND
23478-PeCDF	BDL	1.49e-12	<1.49e-12	ND
123478-HxCDF	BDL	BDL	ND	ND
123678-HxCDF	BDL	2.99e-12	<2.99e-12	ND
234678-HxCDF	BDL	3.69e-12	<3.69e-12	ND
1234678-HpCDF	5.94e-12	3.13e-11	1.87e-11	1.80e-11
1234789-HpCDF	BDL	BDL	ND	ND
OCDF	BDL	2.99e-11	<2.99e-11	ND
Totals - Dioxins				
Total TCDD	BDL	BDL	ND	ND
Total PeCDD	BDL	BDL	ND	ND
Total HxCDD	BDL	BDL	ND	ND
Total HpCDD	BDL	2.99e-12	<2.99e-12	ND
Totals - Furans				
Total TCDF	2.97e-12	7.47e-12	5.22e-12	3.18e-12
Total PeCDF	BDL	1.64e-11	<1.64e-11	ND
Total HxCDF	1.23e-12	2.53e-11	1.33e-11	1.71e-11
Total HpCDF	8.91e-12	4.55e-11	2.72e-11	2.59e-11

[a]Standard deviation.
[b]Below detection limit.
[c]Not determinable.

Table 5.19. Concentrations of Semivolatile Organic Compounds (SVOCs) in the Nonaluminized Ammonium Perchlorate (AP) Propellant Burn Pan Residue.

Analyte	Trials 1 and 2 (combined) (μg/kg)
Benzyl alcohol	59
Diethyl phthalate	67
Di-n-butyl phthalate	81

Table 5.20. Concentrations of Metals in the Nonaluminized Ammonium Perchlorate (AP) Propellant Burn Pan Residue.

Analyte	Trials 1 and 2 (combined) (mg/kg)
Aluminum	140,000
Antimony	BDL[a]
Arsenic	BDL
Barium	11
Cadmium	BDL
Calcium	720
Chromium	1400
Copper	530
Lead	BDL
Mercury	BDL
Nickel	940
Potassium	93
Sodium	180
Titanium	16
Zinc	6

[a]Below detection limit.

Table 5.21. Emission Factors for Target Inorganic Gases from the Burning of Aluminized Ammonium Perchlorate (AP) Propellant.

Analyte	Trial 1 (g/g)	Trial 2 (g/g)	Average (g/g)	SD[a] (g/g)
Real-Time Analyzer				
CO_2	1.96e-01	1.86e-01	1.91e-01	7.26e-03
CO	1.24e-03	1.76e-04	7.08e-04	7.53e-04
NO	2.16e-03	1.59e-03	1.88e-03	4.08e-04
NO_2	2.06e-04	7.09e-05	1.38e-04	9.53e-05
SO_2	5.77e-05	3.69e-05	4.73e-05	1.47e-05
O_3	7.93e-03	-[b]	7.93e-03	ND[c]
SUMMA® Canister				
CO_2	2.03e-01	1.86e-01	1.94e-01	1.21e-02
CO	1.29e-03	2.15e-04	7.52e-04	7.59e-04

[a]Standard deviation.
[b]Pressure transducer failure in ozone instrument.
[c]Not determinable.

Table 5.22. Emission Factors for Volatile Organic Compounds (VOCs) (Assayed using GC/FID[a]) from the Burning of Aluminized Ammonium Perchlorate (AP) Propellant.

Analyte	Trial 1 (g/g)	Trial 2 (g/g)	Average (g/g)	SD[b] (g/g)
Alkanes (Paraffins)	3.21e-06	BDL[c]	<3.21e-06	ND[d]
Alkenes (Olefins)	2.90e-05	1.36e-05	2.13e-05	1.09e-05
Aromatics	3.02e-06	BDL	<3.02e-06	ND
Total Unidentified Hydrocarbons	2.35e-05	2.57e-05	2.46e-05	1.54e-06
Total Nonmethane Hydrocarbons	5.87e-05	3.13e-05	4.50e-05	1.94e-05
Methane	1.76e-05	3.96e-06	1.08e-05	9.66e-06
1,3-Butadiene	BDL	6.60e-08	6.60e-08	ND
Benzene	1.57e-06	2.64e-07	9.19e-07	9.27e-07
Toluene	7.55e-07	BDL	<7.55e-07	ND
Styrene	BDL	3.96e-07	<3.96e-07	ND
Total Nonmethane Organic Compounds	1.03e-04	3.96e-05	7.15e-05	4.51e-05

[a]Gas chromatography/flame ionization detection.
[b]Standard deviation.
[c]Below detection limit.
[d]Not determinable.

Table 5.23. Emission Factors for Volatile Organic Compounds (VOCs) (Assayed using GC/MS[a]) from the Burning of Aluminized Ammonium Perchlorate (AP) Propellant.

Analyte	Trial 1 (g/g)	Trial 2 (g/g)	Average (g/g)	SD[b] (g/g)
Freon® 12	BDL[c]	1.37e-07	<1.37e-07	ND[d]
Methyl chloride	2.39e-07	2.06e-07	2.23e-07	2.31e-08
Vinyl chloride	1.02e-07	6.87e-08	8.55e-08	2.38e-08
1,3-Butadiene	3.41e-08	3.43e-08	3.42e-08	1.32e-10
Ethyl chloride	7.16e-07	2.40e-07	4.78e-07	3.37e-07
Freon® 11	1.37e-07	BDL	<1.37e-07	ND
Vinylidene chloride	6.83e-08	3.43e-08	5.13e-08	2.40e-08
Methylene chloride	9.21e-07	6.87e-07	8.04e-07	1.66e-07
Freon® 113	3.41e-08	BDL	<3.41e-08	ND
1,1-Dichloroethane	3.41e-08	3.43e-08	3.42e-08	1.32e-10
Chloroform	5.46e-07	6.18e-07	5.82e-07	5.09e-08
1,2-Dichloroethane	3.41e-08	BDL	<3.41e-08	ND
Methylchloroform	6.83e-08	1.03e-07	8.57e-08	2.47e-08
Benzene	8.88e-07	1.03e-07	4.95e-07	5.55e-07
Carbon tetrachloride	8.53e-07	8.93e-07	8.73e-07	2.82e-08
Toluene	4.78e-07	BDL	<4.78e-07	ND
Tetrachloroethylene	8.53e-07	1.03e-07	4.78e-07	5.30e-07
Chlorobenzene	2.05e-07	3.43e-08	1.20e-07	1.20e-07
Ethylbenzene	3.07e-07	1.37e-07	2.22e-07	1.20e-07
m-,p-Xylene	4.44e-07	2.40e-07	3.42e-07	1.44e-07
Styrene	BDL	3.43e-08	<3.43e-08	ND
o-Xylene	3.41e-07	BDL	<3.41e-07	ND
p-Ethyltoluene	6.83e-08	BDL	<6.83e-08	ND
Benzyl chloride	2.73e-07	2.75e-07	2.74e-07	1.62e-09

[a]Gas chromatography/mass spectrometry.
[b]Standard deviation.
[c]Below detection limit.
[d]Not applicable.

Table 5.24. Emission Factors for Semivolatile Organic Compounds (SVOCs) (Sampled with High-Volume and PM_{10}[a] Samplers) from the Burning of Aluminized Ammonium Perchlorate (AP) Propellant.

Analyte	Trial 1 (g/g)	Trial 2 (g/g)	Average (g/g)	SD[b] (g/g)	PM10 Sampler Trial 1 (g/g)	PM_{10} Sampler Trial 2 (g/g)	PM_{10} Sampler Average (g/g)	PM_{10} Sampler SD (g/g)
Benzyl alcohol	1.86e-06	1.80e-06	1.83e-06	4.51e-08	BDL[c]	4.46e-07	<4.46e-07	ND[d]
4-Chloro-3-methyl-phenol	4.72e-07	BDL	<4.72e-07	ND	BDL	BDL	ND	ND
a,a-Dimethyl-phenethylamine	BDL	2.24e-07	<2.24e-07	ND	BDL	BDL	ND	ND
Dimethyl phthalate	8.36e-08	4.05e-07	2.44e-07	2.27e-07	BDL	BDL	ND	ND
4-Nitrophenol	2.20e-06	3.14e-06	2.67e-06	6.59e-07	BDL	1.01e-06	<1.01e-06	ND
Diethyl phthalate	2.06e-07	1.03e-07	1.54e-07	7.25e-08	BDL	4.22e-08	<4.22e-08	ND
Di-n-butyl phthalate	4.25e-07	1.85e-07	3.05e-07	1.70e-07	BDL	3.08e-08	<3.08e-08	ND
Butylbenzyl phthalate	5.39e-08	1.36e-07	9.49e-08	5.80e-08	BDL	BDL	ND	ND
bis(2-Ethylhexyl) phthalate	BDL	5.45e-06	<5.45e-06	ND	BDL	BDL	ND	ND
Di-n-octyl phthalate	4.11e-07	6.50e-07	5.31e-07	1.69e-07	BDL	9.67e-08	<9.67e-08	ND

[a]Particulate matter less than ten microns in diameter.
[b]Standard deviation.
[c]Below detection limit.
[d]Not determinable.

Table 5.25. Emission Factors for Semivolatile Organic Compounds (SVOCs) (Sampled with PS[a]-1 Samplers) from the Burning of Aluminized Ammonium Perchlorate (AP) Propellant.

Analyte	Trial 1 (g/g)	Trial 2 (g/g)	Average (g/g)	SD[b] (g/g)
2-Chlorophenol	1.19e-05	1.05e-05	1.12e-05	9.83e-07
Benzyl alcohol	1.71e-06	2.24e-06	1.98e-06	3.75e-07
Acetophenone	1.98e-06	2.57e-06	2.27e-06	4.19e-07
Naphthalene	4.60e-07	2.36e-06	1.41e-06	1.35e-06
2-Methylnaphthalene	7.85e-07	BDL[c]	<7.85e-7	ND[d]
Biphenyl	8.46e-07	2.93e-07	5.69e-07	3.91e-07
Diethyl phthalate	6.16e-07	6.10e-07	6.13e-07	4.10e-09
Di-n-butyl phthalate	1.18e-06	1.05e-06	1.12e-06	9.12e-08
bis(2-Ethylhexyl) phthalate	1.91e-06	5.61e-06	3.76e-06	2.61e-06

[a]Pesticide sampler.
[b]Standard deviation.
[c]Below detection limit.
[d]Not determinable.

Table 5.26. Emission Factors for Metals from the Burning of Aluminized Ammonium Perchlorate (AP) Propellant.

Analyte	Trial 1 (g/g)	Trial 2 (g/g)	Average (g/g)	SD[a] (g/g)	PM_{10}[b] Sampler Trial 1 (g/g)	PM_{10} Sampler Trial 2 (g/g)	PM_{10} Sampler Average (g/g)	PM_{10} Sampler SD (g/g)
Aluminum	9.44e-03	1.15e-02	1.05e-02	1.47e-03	7.37e-03	4.45e-03	5.91e-03	2.07e-03
Antimony	BDL[c]	BDL	ND[d]	ND	BDL	BDL	ND	ND
Arsenic	BDL	BDL	ND	ND	BDL	BDL	ND	ND
Barium	1.25e-05	1.34e-05	1.29e-05	6.35e-07	8.07e-06	8.08e-06	8.07e-06	5.73e-09
Calcium	3.68e-04	3.64e-04	3.66e-04	2.73e-06	3.18e-04	2.66e-04	2.92e-04	3.67e-05
Chromium	8.70e-06	9.13e-06	8.91e-06	3.04e-07	4.14e-06	2.60e-06	3.37e-06	1.09e-06
Lead	4.23e-05	1.01e-05	2.62e-05	2.28e-05	1.98e-05	0.00e+00	9.89e-06	1.40e-05
Mercury	7.96e-08	2.31e-08	5.14e-08	3.99e-08	3.04e-08	3.05e-08	3.04e-08	3.99e-11
Nickel	5.86e-06	6.98e-06	6.42e-06	7.86e-07	3.96e-06	4.81e-06	4.38e-06	6.06e-07
Potassium	3.58e-04	3.69e-04	3.64e-04	7.74e-06	1.80e-04	1.90e-04	1.85e-04	6.68e-06
Sodium	5.49e-04	5.82e-04	5.66e-04	2.36e-05	4.60e-04	4.74e-04	4.67e-04	1.04e-05
Titanium	9.94e-07	5.65e-07	7.79e-07	3.04e-07	2.62e-07	2.93e-07	2.77e-07	2.19e-08
Zinc	6.19e-05	2.33e-05	4.26e-05	2.73e-05	4.31e-05	1.77e-05	3.04e-05	1.80e-05

[a]Standard deviation.
[b]Particulate matter less than ten microns in diameter.
[c]Below detection limit.
[d]Not determinable.

Table 5.27. Emission Factors for Dioxins and Furans from the Burning of Aluminized Ammonium Perchlorate (AP) Propellant.

Analyte	Trial 1 (g/g)	Trial 2 (g/g)	Average (g/g)	SD[a] (g/g)
Dioxins				
2378-TCDD	BDL[b]	BDL	ND[c]	ND
1234678-HpCDD	1.68e-11	BDL	<1.68e-11	ND
OCDD	BDL	BDL	ND	ND
Furans				
2378-TCDF	BDL	BDL	ND	ND
12378-PeCDF	1.68e-11	BDL	<1.68e-11	ND
23478-PeCDF	3.36e-11	BDL	<3.37e-11	ND
123478-HxCDF	1.34e-10	BDL	<1.35e-10	ND
123678-HxCDF	5.05e-11	1.72e-11	3.39e-11	2.36e-11
234678-HxCDF	8.42e-11	2.80e-11	5.62e-11	3.97e-11
1234678-HpCDF	3.71e-10	1.33e-10	2.52e-10	1.68e-10
1234789-HpCDF	5.05e-11	BDL	<5.06e-11	ND
OCDF	2.19e-10	6.89e-11	1.44e-10	1.06e-10
Totals - Dioxins				
Total TCDD	BDL	BDL	ND	ND
Total PeCDD	BDL	BDL	ND	ND
Total HxCDD	1.34e-11	BDL	<1.35e-11	ND
Total HpCDD	5.05e-11	BDL	<5.06e-11	ND
Totals - Furans				
Total TCDF	3.542e-10	BDL	<3.54e-10	ND
Total PeCDF	5.392e-10	3.45e-11	2.87e-10	3.57e-10
Total HxCDF	5.392e-10	9.70e-11	3.18e-10	3.13e-10
Total HpCDF	6.239e-10	2.02e-10	4.13e-10	2.98e-10

[a]Standard deviation.
[b]Below detection limit.
[c]Not determinable.

Table 5.28. Concentrations of Semivolatile Organic Compounds (SVOCs) in the Aluminized Ammonium Perchlorate (AP) Propellant Burn Pan Residue.

Analyte	Trials 1, 2, and 3 (combined) (μg/kg)
4-Nitrophenol	830
Diethyl phthalate	750
Di-n-butyl phthalate	3300

Table 5.29. Concentrations of Metals in the Aluminized Ammonium Perchlorate (AP) Propellant Burn Pan Residue.

Analyte	Trials 1, 2, and 3 (combined) (mg/kg)
Aluminum	360
Antimony	BDL[a]
Arsenic	BDL
Barium	3.9
Cadmium	1.6
Calcium	16,000
Chromium	970
Copper	26,000
Lead	26
Mercury	BDL
Nickel	1400
Potassium	32
Sodium	280
Titanium	2.5
Zinc	20

[a]Below detection limit.

INTENTIONALLY BLANK

SECTION 6. DISCUSSION

The methods developed for testing chemically unique PEP ordnance in the BangBox chamber proved suitable for characterizing the emissions from the OB of double-base and the chlorine-containing AP-based propellants.

The results of the HCl controlled release designed to determine the fate and accountability of chlorine within the BangBox indicated that the real-time instrument had a higher percent HCl accounted for than did EPA Method 26 using midget impinger trains. The amount of HCl accounted for by real-time instruments compared with the amount of HCl released showed a very strong correlation, implying a direct relationship. This indicated that the real-time instruments were well suited for accounting for HCl in the BangBox.

The swatch analysis for the HCl controlled release proved that the swatch material was highly variable in the amount of chlorides that were absorbed. The mass of chlorides absorbed by swatch material had no correlation to the amount of HCl released, implying no direct relationship. As a result, the data obtained from the swatches were of little value in determining the accountability of HCl released in the BangBox, except to indicate that HCl was absorbed into the fabric of the BangBox chamber. However, the rate and nature of absorption could not be characterized.

Looking at the results of the real-time instruments for all trials conducted in this test series indicated that the TECO Model 15 gas filter correlation HCl analyzer had a very strong correlation to the amount of HCl or Cl_2 released ($r = .9721$, p-value < 0.001). The correlation of HCl accounted for and HCl or Cl_2 released for EPA Method 26 using midget impinger trains was strong ($r = .895$, p-value < 0.001). In general, the real-time instrument accounted for more HCl or Cl_2 released than did EPA Method 26.

However, it is unclear as to why the rates of decay for HCl are so much greater for the AP burns than CO_2 (CO_2 was not generated in the HCl released). A possible reason for the difference in the decay rates could be because of the fact that HCl is absorbed to the fabric of the BangBox as was indicated by swatch testing.

A comparison of the swatch fabrics, the material used to construct the BangBox and the fabric proposed for future BangBox construction, over all trials indicated that the amount absorbed by both swatch types was highly variable and did not correlate to the amount of HCl or Cl_2 released into the BangBox ($r = .1985$ for new, $r = -.0798$ for old). In general, these results indicated that swatch testing failed to measure the amount of chlorides absorbed by the fabric of the BangBox.

The results from these and the previous BangBox studies are now being compiled and the resulting database statistically examined to determine if PEP materials can be classified into "emission product families" based on the chemical composition of the PEP material. The statistical analysis will also determine: (1) if the number of background samples and/or field samples collected for each PEP material can be reduced or should be increased; (2) if the target analyte list, sampling methods, or the sample-collecting times should be changed; and (3) if there are artifact pollutants which should be removed from the test data. A database management system, which will provide access to the BangBox data via the DOD Munitions Items Disposition Action System (MIDAS), is also being developed.

SECTION 7. QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

7.1 ON-SITE

Because of the limited time frame and experimental nature of this testing, an independent QA specialist was not on site during testing. However, members of the TSC, as part of their technical oversight responsibilities, observed all aspects of test execution and ensured that applicable LOI were correctly followed.

7.2 LABORATORY

Laboratories performing assays of samples drawn during this test have been participants in developing the BangBox testing system and have undergone repeated audits. Any problems detected over the period of many years were minor and have long-since been corrected. Because each supporting laboratory has well-developed internal QC procedures, which have historically been carefully followed, laboratory audits were not deemed necessary for this test.

SECTION 8. APPENDICES

APPENDIX A. REFERENCES

1. U.S. Army Armament, Munitions, and Chemical Command (AMCCOM), Rock Island, Illinois, Proceedings of the Technical Steering Committee, 1989.

2. 40 CFR 264.601.

3. 42 USC 7661c.

4. U.S. Army Armament, Munitions, and Chemical Command (AMCCOM), Rock Island, Illinois, Final Report, Development of Methodology and Technology for Identifying and Quantifying Emission Products from Open Burning and Open Detonation Thermal Treatment Methods, BangBox Test Series, Volumes 1, 2, and 3, January 1992.

5. U.S. Army Armament, Munitions, and Chemical Command (AMCCOM), Rock Island, Illinois, Final Report, Development of Methodology and Technology for Identifying and Quantifying Emission Products from Open Burning and Open Detonation Thermal Treatment Methods, Field Test Series, Volumes 1, 2A, and 2B, January 1992.

APPENDIX B. ABBREVIATIONS

AMCCOM - U.S. Army Armament, Munitions, and Chemical Command

AP - ammonium perchlorate

CF - correction factor

CFR - Code of Federal Regulations

CP - command post

CVAA - cold vapor atomic absorption

DAS - Data Acquisition System

DIFS - detonation/ignition firings system

DOD - U.S. Department of Defense

DOE - U.S. Department of Energy

DPG - U.S. Army Dugway Proving Ground

ECD - electron capture detection

EMs - energetic materials

EPA - Environmental Protection Agency

FID - flame ionization detection

GC - gas chromatography

HpCDD - heptachlorinated dibenzo-*p*-dioxin

HpCDF - heptachlorinated dibenzofuran

HxCDD - hexachlorinated dibenzo-*p*-dioxin

HxCDF - hexachlorinated dibenzofuran

IAW - in accordance with

ICP - inductively coupled plasma

LAN - local area network

LOI - letter(s) of instruction

MDT - mountain daylight time

MIDAS - Munitions Items Disposition Action System

MS - mass spectrometry

MSAI - Mountain States Analytical, Incorporated

NMOCs - nonmethane organic compounds

OB - open burning

OCDD - octachlorinated dibenzo-*p*-dioxin

OCDF - octachlorinated dibenzofuran

OD - open detonation

OES - optical emission spectrometry

OGI - Oregon Graduate Institute of Science and Technology

PeCDD - pentachlorinated dibenzo-*p*-dioxin

PeCDF - pentachlorinated dibenzofuran

PEP - propellant, explosive, and pyrotechnic

PM_{10} - particulate matter less than ten microns in diameter

ppmv - parts per million volume

pptv - parts per trillion volume

PVC - polyvinylchloride

QA - quality assurance

QC - quality control

RCRA - Resource Conservation and Recovery Act

SERDP - Strategic Environmental Research and Development Program

STP - standard temperature and pressure

SVOCs - semivolatile organic compounds

TCDD - tetrachlorinated dibenzo-*p*-dioxin

TCDF - tetrachlorinated dibenzofuran

TNMOCs - total nonmethane organic compounds

TSC - technical steering committee

TSP - total suspended particulate

USC - United States Code

VOCs - volatile organic compounds

WDTC - West Desert Test Center